UNIVERSITY OF GENT
Faculty of Economics

A SIMULATION-BASED EXPERIMENTAL INVESTIGATION OF A HOSPITAL SERVICE REQUIREMENTS PLANNING SYSTEM UNDER DIFFERENT SOURCES OF UNCERTAINTY

Dissertation submitted in fulfillment of the degree of
Doctor in Applied Economics

by

Paul GEMMEL

Academic year 1994-1995

Thesis supervisors:

Professor Dr. W. Bruggeman
&
Professor Dr. ir. R. Van Dierdonck

To Veerle and Brecht
with whose love and patience all things are possible.
And to my parents.

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"Hospitals, quite as much as the business world, have been hampered by tradition, so that we find it very difficult to map out the sensible course and see when we should break away from old methods. If a thing has always been done a certain way, and has been satisfactory, there seems no reason to change it. There appear to be some things which cannot be done, some wrongs which are in the nature of things and must exist, so that it seems foolish to waste time over impossibilities.

So too reasoned our fathers but a generation ago, and thereby assured themselves that automobiles were impractical and that airships or wireless telegraphy were but dreams. We have already accepted them as commonplaces. And so it comes about that whenever you hear an elder saying "It is impossible" you may know that not far away some youngster is at work doing that very thing."

Minnie Goodnow, "Efficiency in the care of the patient" in Rosenberg, C.E. (Eds.), *Efficiency, Scientific Management and Hospital Standardisation: an Anthology of Sources*, Garland Publishing Inc., New York & London, 1989, p.185.

PREFACE

In 1914 Frank Gilbreth made the remarkable statement that " a hospital is a factory, a health and happiness factory and it ought to be governed by the supreme principle that governs any other factory: the principle of maximum efficiency in relation to output". The statement of Frank Gilbreth was too early in time to have any effect. The principles of full cost reimbursement by government did not give any incentives to hospital managers to think in terms of cost efficiency and cost effectiveness.
Since the seventies, government people are looking for strategies to limit the growth in health care expenditures. They started implementing prospective reimbursement systems and to give financial responsibility to hospital managers. This was the main reason for many hospital managers to start a search for efficiency in health service delivery. First these efficiency efforts are focused on administrative and financial control. Today, there is a shift of the focus from financial control towards 'management of the process' and 'management of resources'. There is an increasing awareness that the complexity of the hospital organisation and the lack of integration in the operations is one of the main barriers for obtaining better efficiency in health service delivery.

Process management and resource management are typical topics covered by the field of operations management. Operations management is a field of study that concerns those managerial decisions where sets of limited resources are combined together in such a way as to be transformed into sets of desired goods and services that help meet the goals of the organisation.

For a long time, it was difficult to apply operations management principles to hospitals because of the lack of a clear product definition. There was no clear vision on what constitutes the product of a hospital. The cost containment efforts urge researcher and hospital manager to think about their final product. This leads to the development of patient classification systems which can be used as a product(-line) definition. A very well known example of such a patient classification system is the Diagnosis-Related Groups. Although there is a lot of discussion about the use of Diagnosis-Related Groups in hospital management, there is no discussion about the value of this particular patient classification system in changing the way all parties to the health care process think about the products of the hospital, the patterns of resource consumption within the hospital, and the way in which the production process should be monitored (Kimberly et al., 1993, p.361). We hope that this study can further stimulate these changes.

The specificity of the hospital organisation - that makes it much more than a 'health and happiness factory'- urge special attention at how operations must be managed. In 1980, Buffa recognises that operations management in service industries (where the hospital sector belongs to) may be industry-specific, since services are so diverse in their nature.

This study wants to contribute to the search for efficiency in hospitals by looking at the problem of integration in the planning of resources and through the application of operations management principles to hospitals. In this perspective, we hope to contribute to the general development of a theory of Hospital Operations Management and to the practice of managing operations in hospitals. Hospital operations management is still a virgin territory and a lot of work needs to be done.

The Operations Management point of view must be differentiated from the Operations Research point of view. The field of Operations Management has evolved from a purely descriptive origin through the Management Science/Operations Research (MS/OR) phase to a functional field of management. The MS/OR phase provided the scientific methodology necessary to give the Operations Management field a scientific state (Buffa, 1980). A large number of articles have been published using MS/OR in hospitals (Butler, 1995). There are two problems with these MS/OR studies: (1) they are typical micro-studies of local subsystems without looking at other subsystems and (2) these studies have failed to discuss behavioural and managerial aspects of implementation.

This study uses an MS/OR approach (namely simulation) as the major research tool. Nonetheless, we have tried to overcome the two major critics on this kind of study.
While the traditional MS/OR studies in hospitals focus on the scheduling of one specific resource (e.g. operating room schedules), we look at the interrelationship between different resources (such as operating room, beds and nurses). The demand for hospital services is treated in terms of all resource requirements associated with a given product-line (patient group) with the objective of balancing the utilisation of work-force and facilities resources. The approach in this study speaks against the local optimisation of the resources in local subsystems. We argue that there are many dependencies between the resources in a hospital and between the resource requirements and the patients which are treated.

Discussing the behavioural and managerial aspects of implementation in the case of MS/OR studies starts with evaluating the credibility of the model used. The modelling technique used in this study is simulation because this kind of models can be made more realistic than analytical models, i.e. they are able to better capture the actual characteristics of the hospital or it is not necessary to make unrealistic simplifying assumptions. We further invested a lot of time in trying to obtain a credible model. First we investigated the planning process in three American hospitals in order to better understand the problem of integrated planning of resources. Second, we did an in-depth study of the service delivery process in a cardiac surgery unit within a Belgian university hospital in order to find out which operating factors are real barriers for a product-line based

planning of resources. Third we spent a lot of time at verifying and validating our simulation model.
One other example can illustrate our continuous concern for credibility. We deliberately choose to design a system for planning of the resource requirements in such a way that the required data input is routinely available in (Belgian) hospitals.

The operations management society calls for bridging the gap between practice and theory. The approach in this study shows that empirical research and MS/OR studies are not necessary contradictions.

We believe that an important contribution of a doctoral dissertation is its boundary spanning field of interest. The cross-fertilisation of the knowledge present in such areas such as medical informatics, operations management and hospital management offers a way to break the mental set of the existing theories.

It is impossible to perform a doctoral dissertation without the support of many different people. I thank professor dr. R. Van Dierdonck, professor dr. W. Bruggeman and professor dr. V. Smith-Daniels for their professional guidance during the realisation of this work. Certainly professor Van Dierdonck vigorously encourages this kind of study and was personally involved in some aspects of the conceptual design. Professor Smith-Daniels has given me the opportunity to spend one year at the College of Business of the Arizona State University (US.). Although I personally experienced the disadvantages of the American health care system, the theory and practice of hospital management is strongly developed in the US. This is a consequence of the very dynamic environment in which hospitals operate. I want also thank some professors at the Health Care Administration Department of this College of Business to introduce me in three American hospitals.
Further I want to thank the chief executive officers of the different hospitals involved in the preliminary study and the in-depth case study. They have given me the permission to interview many different people in their organisations and were supportive for some ideas underlying this study. I am also grateful that the people in the organisations were prepared to spend some of their valuable time with me to openly discuss the topics. More specifically I want to thank the medical informatics department of the Belgian university hospital and the cardiac surgery unit in the same hospital for their efforts to help me to collect the data for the research. I want also thank my colleagues on the Production and Technology department of the Vlerick School of Management for their useful input. Last but not least, a special word of thanks goes to my wonderful wife Veerle for the moral support and for the many hours that she has listened to my problems. A doctoral dissertation is not a product of an individual but of a group of people believing in the same goal.

Finally it is not possible to spend a lot of time at a doctoral dissertation without financial support. During three years the Intercollegiate Centre for doctoral studies in Management Science (ICM) has given me a grant to perform the study. I am very grateful for this financial contribution and hope that this doctoral dissertation may lead to the further development of management science.

Paul Gemmel
Gent, June 22, 1995

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ICD-9-CM = The International Classification Of Diseases, Ninth Revision, Clinical Modification

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GLOSSARY

ANOVA	Analysis of variance
ADRG	Adjacent DRG
AP-DRGs	All patient DRGs
APR-DRGs	All patient refined DRGs
BOM	Bill of materials
CABG	Coronary artery bypass grafting
CC	Comorbidities and complications
CEO	Chief executive officer
CPM	Critical path method
CSI	Computerised Severity Index
CVRP	Cardiac valve replacement procedure
DRG	Diagnosis-related Groups
Dx	Diagnosis
EKG	Electrocardiogram
HAM	Hospital activity matrix
HCFA	Health Care Financing Administration
HSRP	Hospital service requirements planning
ICD-9-CM	International classification of diseases, ninth revision, clinical modification
ICU	Intensive care unit
LOS	Length of stay
MADCUR	Mean absolute deviation between the actual discharge date and the most recently updated scheduled discharge data
MADHIST	Mean absolute deviation between the actual discharge date and the original scheduled discharge date
MDC	Major diagnostic categories
MPDBED	Mean percentage deviation in actual bed requirements from estimated bed requirements
MPDRX	Mean percentage deviation in actual chest X-ray requirements from estimated chest X-ray requirements
MPS	Master production schedule
MRP	Material requirements planning
MRP II	Manufacturing resources planning
MRU	Measures of resource use
MVGs	Minimal nursing data
OR	Operating room
PERT	Program evaluation and review technique

PMCs	Patient Management Categories
PMPs	Patient management paths
RDRGs	Refined DRGs
RVU	Relative value units
Rx	Chest X-ray
SII	Severity of Illness Index

2191D	Cardiology, preoperative
8140C	Heart surgery, medical, preoperative
8325D	Intensive care, general, preoperative
8327C	Intensive care, heart surgery, preoperative
2191DO	Cardiology, postoperative
8140CO	Heart surgery, medical, postoperative
8325DO	Intensive care, general, postoperative
8327C2	Intensive care, heart surgery, postoperative, second attendance
8140CO2	Heart surgery, medical, postoperative, second attendance
8327C3	Intensive care, heart surgery, postoperative, third attendance
8140C3	Heart surgery, medical, postoperative, third attendance

INTRODUCTION

In this introductory section, we describe the problem and present the overall research framework. The main goal of the section is to give the reader some general framework which can be used as a guideline in the further development of the research. Finally we introduce the different parts and sections.

Problem statement

The whole hospital sector is under growing external pressures to operate in an efficient way. This study is a contribution to this search for efficiency from an operations management point of view. Operations management is a field of study that concerns those managerial decisions where sets of limited resources are combined together in such a manner as to be transformed into sets of desired goods and services that help meet the goals of the organisation (Saladin, 1984). Because the goals are different according to the nature of the organisation, we further limit the scope of the study to inpatient acute care hospitals.

After an extensive review of the literature and after a preliminary study in three American acute care hospitals, we found that one of the main barriers in obtaining higher efficiency in the hospital operations is the lack of an integrative approach in the process of matching the capacity of several hospital resources (such as beds, operating rooms and nursing staff) with the demand (i.e. the inflow of patients). Matching supply and demand is the core task of capacity management.

Service requirements planning in inpatient acute care hospitals is a process which supports capacity management decisions by treating demand for hospital services in terms of all of the resource requirements associated with a certain patient and with the objective of balancing and stabilising the utilisation of resources . The aim of hospital service requirements planning is to break through the dilemma between better capacity utilisation and shorter throughput times. Better capacity utilisation does not necessarily mean higher utilisation, but means less fluctuation in the daily utilisation or workload pattern. Further in this study, we will argue that workload fluctuation is recognised as one of the major problems in obtaining higher efficiency in health service delivery.

To perform the task of service requirements planning in hospitals, Roth et al. (1992, 1995) propose a decision support system which is called HSRP (Hospital Service Requirements Planning). The design of this system is based on four important assumptions:

1. HSRP requires the definition of patient groups which are homogeneous as to their consumption of hospital resources. In this study we have decided to use the Diagnosis-related Groups (DRGs) as a way to define resource-homogeneous patient groups.
2. There are relationships between the capacity of different service units in a hospital and these relationships must be reflected in the planning system. We use the term 'capacity structure' for such relationships. In HSRP, the capacity structure of the hospital must be built in. Tools such as 'bill of resources' and 'MRP mechanism' are used for this purpose.

3. Clinical and financial data on the patient can be merged so that measures of resource use can be obtained.

4. The planning algorithm of HSRP is based on concepts which are transferred from the manufacturing planning and control environment to the hospital planning and control environment. Master Production Scheduling (MPS), bill of resources and Material Requirements Planning (MRP) are the three most important manufacturing concepts which has been transferred.

The HSRP as proposed by Roth et al. (1992) is a conceptual framework and requires further validation to find out whether the transferred concepts are useful and meaningful. This study brings some validation taking into account the differences between the hospital and manufacturing environment. The general research framework is shown in figure I.

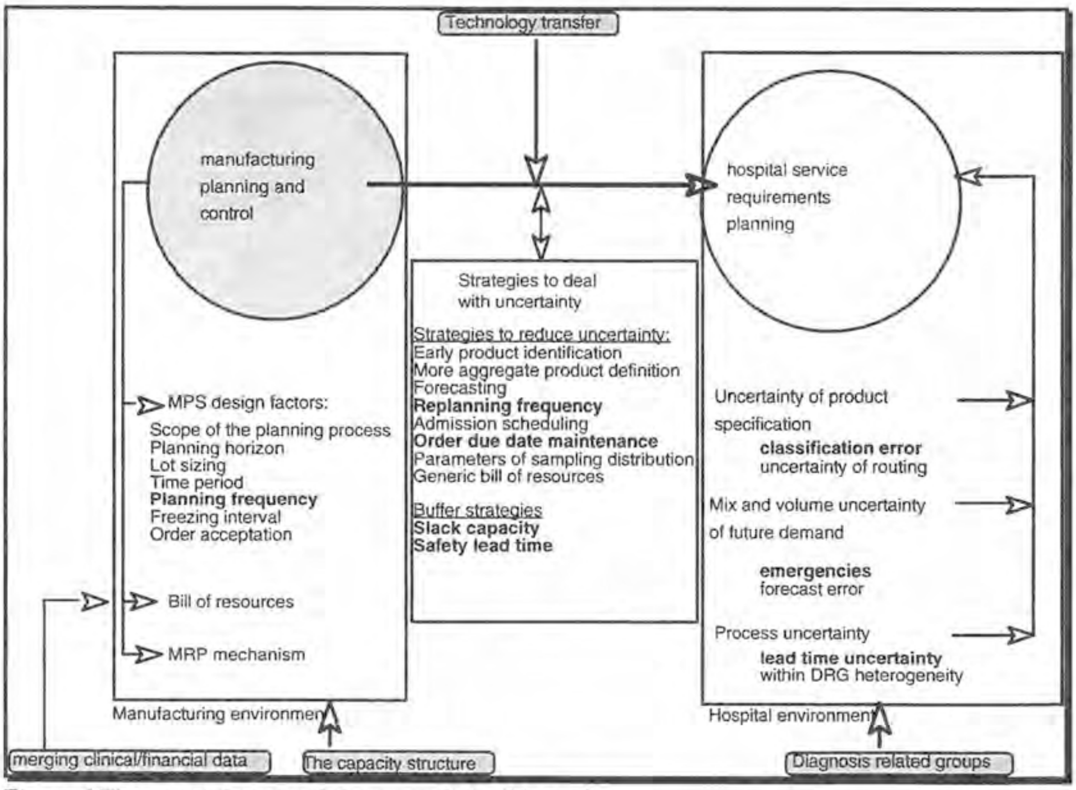

Figure I The general research framework for this study.

The main difference between the hospital and manufacturing environment is that there is a lot more uncertainty in a hospital than in the manufacturing environment where the transferred concepts are traditionally applied. Based on an in-depth study of the service delivery process in a cardiac surgery department in a University hospital, we identified the major sources of the uncertainty in the hospital operations (see right part of figure I).
We also identify strategies to deal with these different sources of uncertainty. A distinction is made between strategies to reduce uncertainty and strategies to buffer against uncertainty (see middle part of figure I). These strategies can be used with or incorporated in the HSRP system.

The basic research question is formulated as follows: "What is the performance of the HSRP system (based on manufacturing planning concepts) in a hospital environment taking into account the different sources of uncertainty and the different strategies to reduce or to buffer against uncertainty ?". We want to evaluate the feasibility of the HSRP system in hospital environments taking into account that some design factors of HSRP can be changed in order to better fit a specific hospital environment. The specificity of the hospital environment is determined by the extent to which the different sources of uncertainty are present in the hospital environment. The most important result in the study is the identification of the factors (sources of uncertainty and/or design characteristics) which significantly determine the performance of the HSRP system. Because of the large number of factors, we have made a selection of factors which are included in this particular study (see the bold factors in figure I). The basic research question implies that the nature of this research is more exploratory than confirmatory.

Research outline and outline thesis

Because the HSRP system is in no way an operational planning system, we cannot set up an experimental design or quasi-experimental design through the implementation of the system in an actual operating hospital. When experimentation with the actual system is not possible, we have to experiment with a model of the system. We have chosen to simulate the behaviour of the real system, i.e. (a part of) an actual operating hospital. The feasibility question of HSRP is tested in this 'artificial' environment. Furthermore, because HSRP is not operational, we have also simulated the working of this service requirements planning system (see figure II).
In order to be able to simulate the operating system of a part of a hospital, we have performed an in-depth study of the service delivery process in a cardiac surgery unit of a University hospital in Belgium. Figure III summarises the research outline for this study.

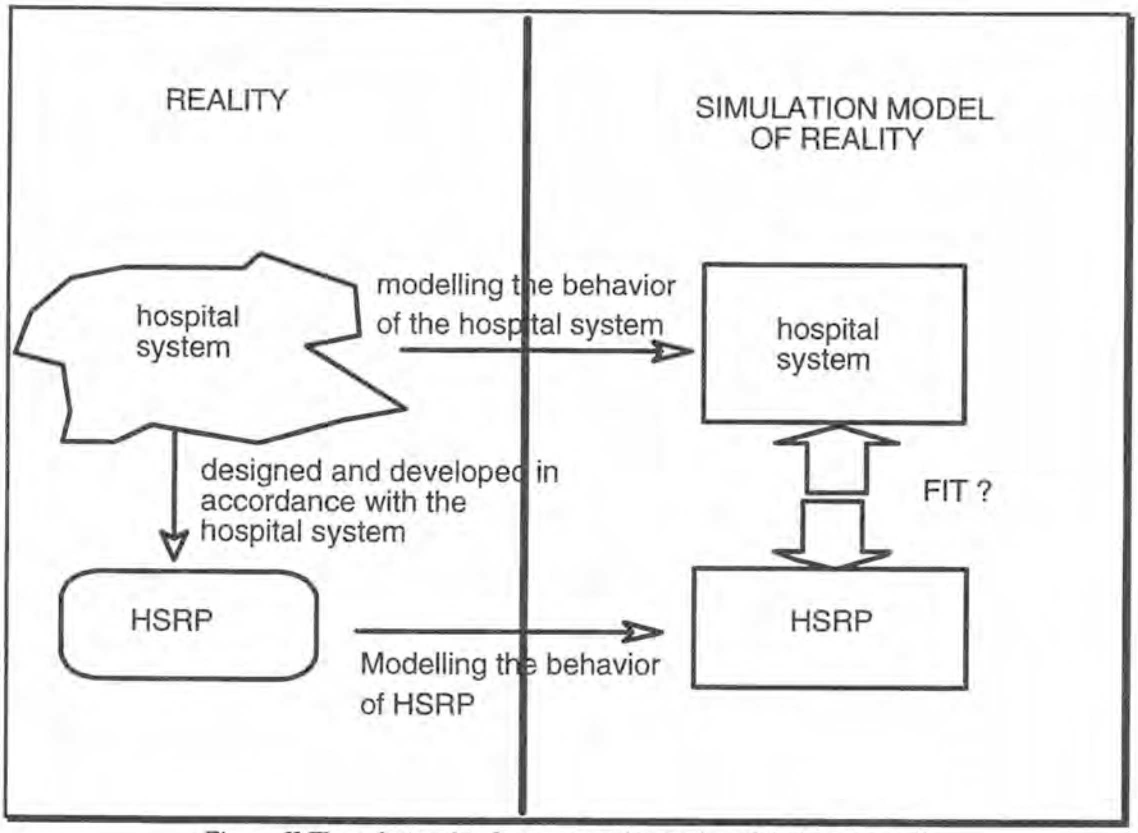

Figure II The relationship between reality and model(s) in the study

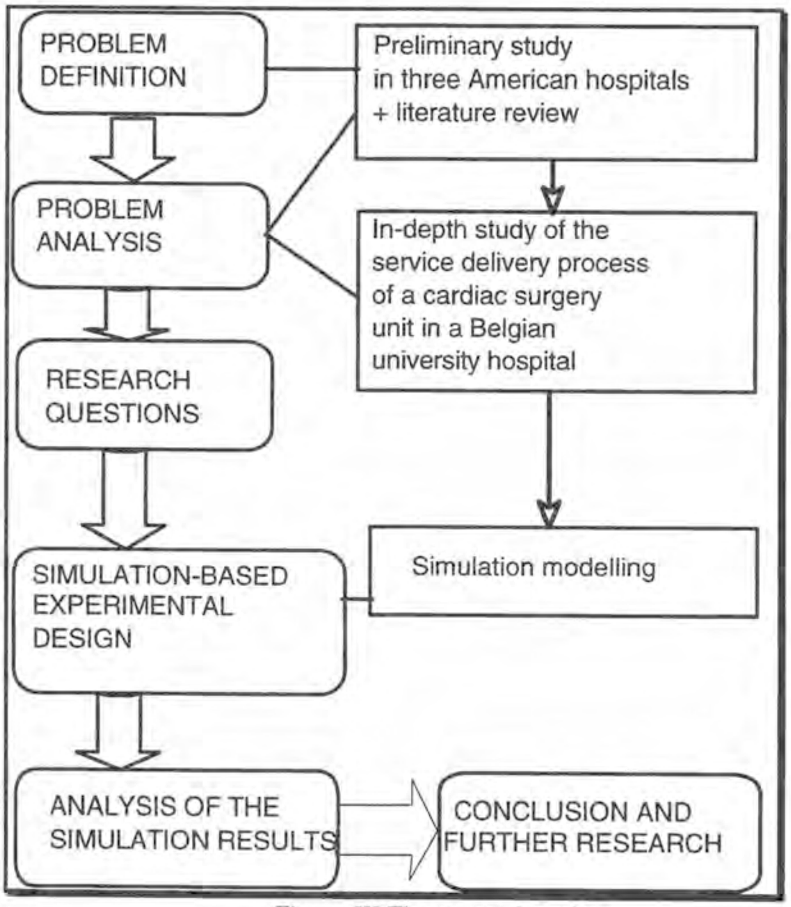

Figure III The research outline

In part 1, we further define service requirements planning by looking at the literature and give some motivations why a system such as HSRP must be developed. We have identified five reasons why to study this topic: (1) growing external pressures for hospital to operate in an efficient way; (2) the lack of integration in the organisation of the hospital process; (3) a growing interest for integrated capacity management; (4) the thinking and the development of 'what constitutes the product of a hospital' and (5) the natural outcome of research going on for years.

In part 2, we describe the different design characteristics of HSRP. HSRP is developed using some very clear ideas about how a system of service requirements planning should work in a hospital environment: (1) the system focuses on patient flows and Diagnosis-related Groups; (2) the system requires a description of the capacity structure of the hospital; (3) the planning system needs the input of case-based resource management data and (4) the planning uses concepts which are transferred from the manufacturing planning and control theory. In the same part, we introduce the different performance measures used to evaluate the performance of HSRP.

After stating the basic research question in part 3, we describe the HSRP framework. Central in this description are the Master Production Schedule (which drives the whole system), the bill of resources and the MRP mechanism. The working of HSRP is further illustrated with an example. We then determine the different factors which play a role in the study: (1) design factors of HSRP (where many of these design factors are 'borrowed' from the manufacturing planning and control theory); (2) sources of uncertainty in the hospital environment and (3) strategies to deal with these different sources of uncertainty. In order to deal with uncertainty, a three-factor classification scheme is used: product specification uncertainty, mix and volume uncertainty of future demand and process uncertainty.

In part 4, we further specify the experimental design by describing the factors and factor levels, the responses or performance measures and the hypotheses. The different factors, their levels and the responses are combined to define 128 different treatments (or different configurations). We introduce the method of simulation-based experimental investigation. As previous stated, a simulation model has been developed. In part 4, we also describe the logic behind the simulation model and the structure of the simulation program. We spend a lot of time at the validation and the verification of the model because it greatly determines the credibility of the results. Finally we present the different aspects related with the statistical output of the simulation model such as warm-up period and autocorrelation.

An important question in the analysis of the simulation results in an experimental design is whether the main and interaction effects are significant or not. In part 5, we show the statistical techniques which can be used to determine the significance. After presenting and discussing the results of this specific study, a one-way analysis of variance (ANOVA) is performed to determine significant main and interaction effects. In presenting these results, a distinction is made between the technical performance of HSRP and the planning performance, and between bed resources and chest X-ray resources. After presentation, we discuss the results using the framework of the hypotheses.

In part 6 we formulate conclusions, further research questions and management implications.

1. PROBLEM DEFINITION

In this section we further define the problem as stated in the introductory section. First we give some arguments to limit the study to inpatient acute care hospitals. In the following steps, the task of service requirements planning is reconsidered and positioned in the literature. Finally, we give some motivations for doing this kind of research.

1.1. Research field: inpatient acute care hospitals

A hospital is " a facility offering inpatient overnight care and services for observation, diagnosis and active treatment of an individual with medical, surgical, obstretical, chronic or rehabilitative condition requiring the daily direction and supervision of a physician" (Griffith, 1992). Observation, diagnosis and treatment are delivered in a multi-disciplinary environment and within an appropriate medical, medical-technical, nursing, paramedical and logistic framework (Beeckmans, 1986). By adopting this definition, we emphasise the fact that the primary function of a hospital (which discriminates it from any other health care organisation) is to deliver inpatient services (Shortell et al., 1988). This excludes all outpatient facilities such as ambulatory care units and one-day clinics. [1] Shortell et al. (1988; pp.16-17) compared inpatient and outpatient facilities and found some remarkable differences:

- Inpatient hospitals face a more dynamic and complex environment than other health care organisations. Therefore they need a different set of management structures and processes.
- The hospital's mission and goals are primarily treatment oriented (as opposed to the more diagnosis/prevention orientation in other health care organisations). Further in the text we will argue that the distinction between the diagnostic process and the therapeutic process is very important for service requirements planning.
- In inpatient hospitals, goals are not particularly well integrated or congruent. This implies that the managerial task of service requirements becomes more difficult.
- The degree of task interdependence is much higher in inpatient hospitals than in ambulatory care centres. This implies the need for other co-ordination and control mechanisms.

[1] There is recently an important shift from inpatient care to one-day clinics. At the outset of the study, the phenomenon of same-day surgery was not as popular as it is now. In the future, it is interesting to further study the impact of this shift on service requirements planning.

- The manager-physician relationship in hospitals is in general relative impersonal and highly structured while this relationship in ambulatory care is more personal and structured.

- The length of the service encounter is completely different in inpatient and outpatient facilities.

These differences have clear operational consequences (e.g. for admission scheduling) so that the choice for one of the two facilities seems obvious. The higher task interdependence and the lower integration make the inpatient hospital a more interesting study area as compared to the outpatient facilities (as far as service requirements planning is concerned).

Within the inpatient hospitals, a further distinction can be made between acute care, long term care and psychiatric care. Several authors argue that these types of care are so different that the associated pathologies cannot be caught by one patient classification system (Cameron, 1985; Fries et al., 1985). Classifying patients is one of the most important characteristics of the service requirements planning system presented in a later section. If we have to cope in this research with several patient classification systems used in one hospital, the complexity of our study will increase enormously. Furthermore, the classification system for acute care patients is the most operational and widely used (Lichtig, 1986, p.3). For instance, in Belgium, only patient classification systems for acute care have been widely diffused.

The above arguments support our choice for the acute care hospital as the central point of focus.

A hospital as a system organises a set of resources -personnel, materials, facilities and/or information - to perform designated functions in order to achieve desired results (see Reisman, 1979). Basically this means that we use the input-conversion process-output framework to describe the health care service delivery in a hospital in terms of the resources required, the work methods and procedures used, and in terms of the results. A distinction is generally made between the diagnostic process and the therapeutic process. The goal of the diagnostic process is to provide an explanation or cause of the signs and symptoms (HBS, 1985). The therapeutic process involves an act of intervention with the purpose of altering the status of the patient (HBS, 1985).

The two-part hospital production function as described by Chilingerian et al. (1990) and Fetter (eds., 1991) has been adopted as a basic model of hospital production in this study (figure 1.1.). "*The first function is to convert raw materials (labour, supplies, equipment) into standard*

outputs (meals, clean linens, laboratory procedures, medications)" (Fetter, eds., 1991, p.9). These standard outputs are intermediate outputs or ´services´. The second function is *"to accept one at a time human beings who have a problem, a disease or a disorder, and to evaluate and treat, through physicians and other professionals, the problem and the patient. Under the direction of these professionals, the institution provides a set of goods and services deemed appropriate to the diagnosis and treatment of the illness* "(Fetter, eds., 1991, p.10).
It is this bundle of goods and services that is defined as the product of the hospital.

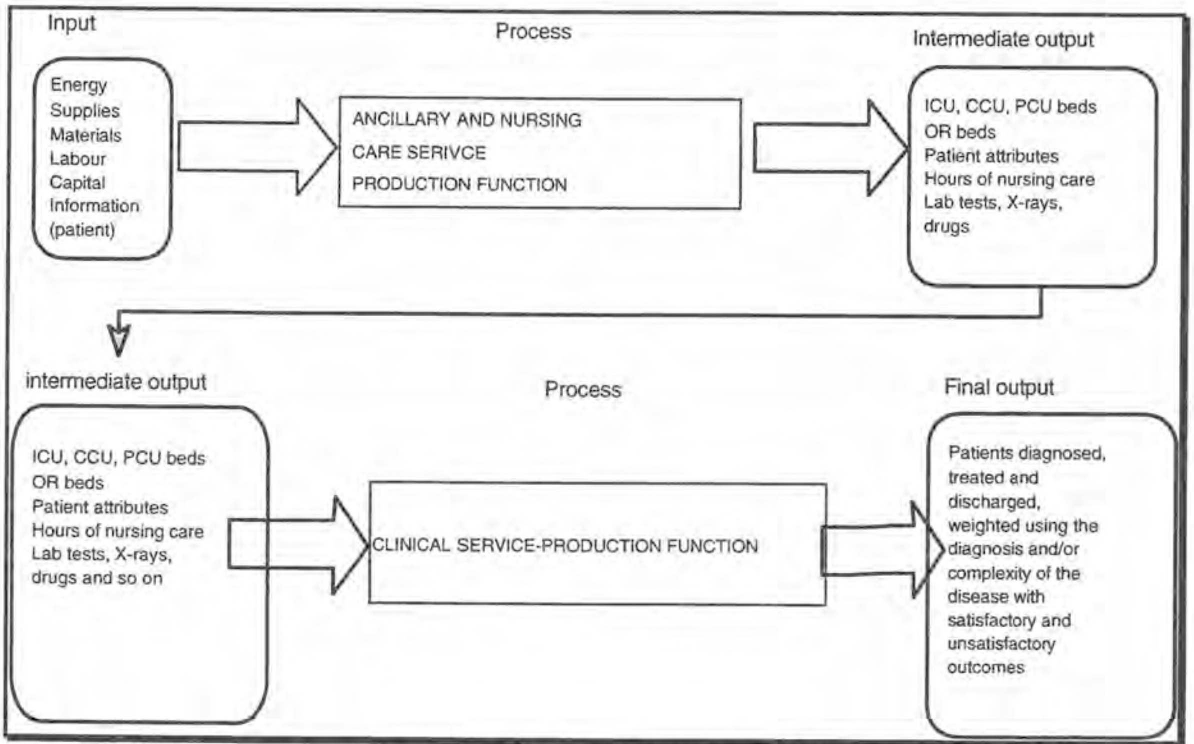

Figure 1.1. The two-part hospital production function (adapted from Chilingerian et al., 1990)

The main distinction between services and goods is that services as intermediate output cannot be stored in inventory. This means that services must be produced at the moment that they are consumed (Chase, 1978). The amount of services that can be produced is constrained by the availability of these resources. Here a distinction must be made between material resources and capacity resources. Capacity resources are resources which are used but not consumed during the production of an end item (Vissers, 1993, p.78). A capacity resource has a certain capability to generate production (Vissers, 1994, p.15). This capability in conjunction with the availability determine the output rate. Examples of capacity resources are facility resources (such as equipment) and workforce resources. In comparing the importance of capacity and material resources in a hospital, it is important to note that workforce resources alone consume more than 50% of the yearly budget of the hospital. As an example we have listed in table 1.1. the number of people working in a University hospital with approximately 1000 beds. Furthermore capacity resources such as specialists, operating rooms and beds have been recognised as the leading resources in the production of inpatient health care (Vissers, 1994). In a recent study, it is recognised that the provision of nursing services is the primary reason for hospitals to continue to exist (Siferd, 1992). These observations allow to conclude that capacity resources have a much higher strategic importance in the management of resources in hospitals.

Table 1.1. Total number of personnel in a University hospital

Specialists	420
Paramedics	252
Nurses	1222
Administrative personnel	315
Technical personnel	883
Total number of personnel	2953

From an operations management point of view, a hospital can be described as being a network of service units with finite capacity through which patients are flowing (Cohen et al., 1980). The specific flow (or routing) of a particular patient through this network depends on its service-mix requirements. This means that it may be difficult to identify a specific work flow pattern through the shop. Based on this operations management view, the hospital process can be compared with a job shop. Typical characteristics of a job shop are the initiation of the process by the customer and the wide variety of jobs (with different sequences of tasks) and the dilemma between the availability of capacity service units and short throughput times (Berki, 1972; Fändel et al., 1989; Roth et al., 1992). This dilemma is stronger in an environment where demand is time-dependent, production and consumption are simultaneous and the production units are perishable (Chase, 1978). Management of the patient flow by admission and throughput scheduling is a necessary condition to obtain lower variability in the daily utilisation (Shukla, 1985; Groot, 1991 and Siferd, 1992).

1.2. Research topic: Service requirements planning

The term 'service requirements planning' in a hospital context has been first introduced by Roth et al. (1992) as hospital-wide planning with an emphasis on integration of resources across different hospital departments. Service requirements planning in hospitals is a process which supports capacity management decisions by treating demand for hospital services in terms of all of the resource requirements associated with a certain patient and with the objective of balancing and stabilising the utilisation of resources (Smith-Daniels et al., 1988).

Based on this definition, we deduce that service requirements planning is a specific aspect of capacity management in hospitals. Capacity management deals with decisions about the availability of capacity at a certain point in time . Different decisions are recognised based on two criteria: the horizon that the decisions are spanning (long-range (> 1 year), medium-range (6-12 months) and short-range (< 6 months)) and the kind of capacity which is studied (workforce and facility resources). Long-range decision mainly concern acquisition decisions while medium- and short-range decisions cover allocation decisions. Based on these classification criteria, Smith-Daniels et al. (1988) have distinguished the capacity decision themes as shown in table 1.2..

Table 1.2. Capacity decisions themes in the literature (Smith-Daniels et al., 1988)

	Facility resources	Work-force resources
Acquisition decisions	Facility location and aggregate capacity size	Hospital staffing Ambulatory care staffing
Allocation decisions	Inpatient admissions scheduling Surgical facility scheduling Ambulatory care scheduling	Work-force scheduling

Acquisition decisions are the basic task of capacity planning (Vissers, 1993, pp. 80-81). The fundamental goal of capacity planning is to match demand and supply at the hospital level, in aggregate terms and for a planning horizon of at least one year. Capacity planning determines the physical constraints on the quantity of services that can be delivered and the flexibility of the system to respond to changes in demand (Smith-Daniels et al., 1988). The decision which determines the total budget to be spent on nursing personnel at the level of the hospital is an example of a capacity planning decision. The determination of the aggregate size of the hospital in terms of number of beds is another example.

In the nearer horizon, capacity is allocated to the different departments/specialities in the hospital (Vissers, 1993, p.80). On this level, a quantity of resources is allocated to units and the appropriate resource input mix is determined so that customer goals are attained and budgetary limits are not exceeded (Smith-Daniels et al., 1988). For example, the nurse staffing decision determining the appropriate size and skill mix for each nursing unit results in an allocation of the available budget (Warner, 1976).

In the case of capacity scheduling, the resources allocated to a department are further assigned either to specific time periods or to specific patients or to specific tasks. This leads to the development of a schedule which is a (time-phased) overview of the allocation of (in the near future) available resources to time-periods, patients or tasks. An example of this kind of decision is the nurse schedule which determines when each nurse will be on or off duty, and on which shift each will work when on duty, taking into account weekends, vacation, ... (Warner, 1976).

Because of uncertain events, reallocation or rescheduling of resources may be necessary. The allocation of a float pool of nurses to units based on non-forecastable changes in the need on the units and on absenteeism is an example of the required daily adjustments (Warner, 1976)

In the framework of Smith-Daniels et al. (1988), allocation decisions cover capacity allocation, capacity scheduling and daily adjustments. Vissers (1994, p.74) calls the combination of capacity allocation and capacity scheduling 'time-phased resource allocation'. In practice it is not always easy to make a distinction between allocation, scheduling and adjustments.

Hospital service requirements planning as a tool supports allocation decisions. Hospital service requirements planning allocates the capacity of several resources to patients before or at admission with the aim of predicting the (work)load of the different resources.

In service requirements planning, it is not only important to match capacity of resources and demand, but it is equally important to match the capacity of one resource with the capacity of other resources. In a hospital, several resources (e.g. beds, operating room, nurses) are used and those resources (and thus also the capacity of the resources) are linked together for the treatment of a particular patient (Vissers, 1994). In other words, fluctuation in the utilisation pattern of one resource leads to fluctuation in the utilisation pattern of another resource. Furthermore, limitations on the capability of one resource to serve patients has an impact on the service capacity of other resources (Siferd, 1992). We define the relationship between the capacity of several resources as the capacity structure of the hospital. Hospital service requirements planning takes into account the capacity structure when scheduling admissions and throughput.

The output of hospital service requirements planning is a time-phased resource profile (HBS, 1975) showing the daily (work) load of the resources needed to treat a certain flow of patients. Using such a resource profile, timely decisions can be taken to avoid too much fluctuations in the (work)load pattern. Examples of such decisions are rescheduling of patients, planning admissions on days with lower workload or changing the capacity level...

1.3. Literature review on service requirements planning in acute care hospitals

Smith-Daniels et al. (1988) have made an extensive literature review of studies on the different capacity decision themes in table 1.2. The studies on inpatient admission scheduling most closely relate to the subject of service requirements planning. Smith-Daniels et al. (1988) have identified the use of analytical as well simulation models in solving the problem of admission scheduling. The major topics covered in these studies are (Smith-Daniels et al., 1988): (1) the determination of slack capacity for emergency patients; (2) the estimation of the patient length of stay and (3) the estimation of the service-requirements of patients. In fact these three topics represent different sources of uncertainty in the service delivery process in hospitals. Furthermore, most of these models focus on maximising the utilisation of bed resources and neglect the other hospital resources (Smith-Daniels et al., 1988).

As indicated earlier, we do not cover capacity management in an ambulatory care setting. Furthermore we are only interested in allocation decisions and more specifically in models which simultaneously consider the use of several resources. Based on this more narrow scope, we have reviewed several other studies.

Offensend (1972) was the first author to compare admission policies based on patient census and nursing work load. One conclusion of this study is that important savings can be realised by basing the admission decision on information about the nursing workload. The major factor contributing to this saving is that a workload based system allows to take into account patient differences (Offensend, 1972). In a more recent study, Shukla (1985; 1990) compares an admission scheduling policy based on workload indices on nursing units with an admission scheduling policy based on the census of the nursing units. One finding was that the former scheduling policy provides a stable workload pattern within a nursing unit and equitably distributes the work among the units. In their review study of surgical scheduling, Magerlein et al. (1978) remark that operating room capacity has received little attention in admission scheduling. "*A vast majority of scheduling systems either ignore surgical patients, schedule a fixed number per day, or schedule patients until an OR time constraint is reached. In doing so, the systems fail to consider either the OR time required by the cases or the demand for other hospital services (e.g. beds, nursing time) generated by surgical patients*[2]" (Magerlein et al., 1978).

In an earlier study, Luck et al. (1971) report the problem of uneven workloads on some paramedical departments They further indicate that changes in the clinic timetable are necessary to produce a steady flow overall in the hospital. They introduce the concept of the Hospital

[2] OR = Operating room

Activity Matrix (HAM) which is a table of numbers that relates the category of patients entering the hospital system and their use of resources (Luck et al., 1971). In such an activity matrix, kind of patients (e.g. general surgery, paediatrics.) are linked with the consumption of particular resources (such as beds and X-ray exams). The data in such a HAM is an important input in a time-table. A time-table is a schedule in which resources available on a certain day are allocated to specialities or departments. The study of Luck et al. (1971) emphasises the importance of workload balancing between paramedical departments. In his doctoral study (1994), Vissers has adopted this approach of workload balancing not only for balancing resources between departments, but also for balancing resources at the level of individual specialities (Vissers, 1994, p.24). The main contribution of the study of Vissers (1994) is that he recognises that variations in the use of resources over days within the week are caused by the way resources are allocated and that these allocations must be co-ordinated because there is a dependency between resources and between the different schedules (time-tables) used to allocate resources to patient flows. He further develops a set of models which can support resource allocation decisions for different capacity sources in the hospital. Several case-studies show the results of implementation of these decision support systems in a number of case hospitals. The study of Vissers (1994) is limited to 'time-phased resource allocation' and does not consider the management of the patient flow (throughput scheduling).

Hancock et al. (1984) use admission simulation to stabilise the workload of ancillary facilities. Using the Admission Scheduling and Control System Simulator (Hancock et al., 1984), they were able to simulate patient flows under a number of scenarios and to determine the workload of 19 different ancillary facilities (such as biochemistry laboratory and physical therapy) (Hancock et al., 1984). One of their conclusions was that the variation in average load by day of week was different for each of the ancillary departments. "Thus, no single inpatient admission policy would provide a stable workload for all 19 departments" (Hancock et al., 1984). Interesting in the studies of Shukla and Hancock et al. is that they recognise that the flow of patients together with their service requirements must be taken into account at the moment that admissions are scheduled.

Much earlier Hearn and Bishop (1970) recognised the importance of patient specific service requirements when they developed a model using a patient profile defining the pattern of care required and the logical sequence of necessary investigations and treatments. The model allows to collect statistics on the use of facilities. They found that there are three categories of service items (Hearn et al., 1970):

1. Fixed service items which occur on a particular day of the stay of a patient. They can be characterised relatively with respect to the admission day.

2. A sequence of service items which is a list of logically related items of service which must occur in a certain sequence. The time lapse between the items in the sequence can be known or not.

3. Independent service items which are not part of a sequence and where timing is not critical at all.

Valinsky (1974) reports on other studies which link patient flow, service requirements and facility utilisation. The most important is the work of Fetter and Thompson (1972). They consider the hospital as a network of subfacilities, each possessing its own resources, as well as sharing some in common with other subfacilities. Although their model was more conceptual than practical, their ideas are interesting. They wanted to predict the beddays and other important resources consumed by a patient as a function of definable patient attributes. Therefore, they developed a patient classification system (called AUTOGRP (Mills et al., 1976) [3]). Each patient class is defined by a path with each node on the path representing a facility. In an earlier study (1969), Fetter and Thompson recognised the need to simulate the flow of patients using path definitions to predict occupancy and utilisation of a given set of facilities. In this study (1969) they described a (progressive patient care) hospital as " a network of patient paths where the holding time at each node is a probability distribution which is a function of both the patient path and the node" (Fetter et al., 1969). The interesting point in the study of Fetter et al. (1969) is that they believe that the transfer of patients from one state (zone of care) to another is dependent on the patient's entire past history (the sequence of locations occupied by the patient to date). In other words, they do not believe in the assumption that patient movement can be modelled as a semi-Markov process [4]. This assumption has been used by different authors (Thomas, 1968; Kao, 1972 and 1974; Cohen et al., 1980; Cohen, 1980; Hershey et al., 1981; Weiss et al., 1982; McFadden and Huq, 1992) to describe the movement of patients in the so-called progressive patient care facilities. In a progressive patient care facility, changes in the condition of patients are marked by their physical transfer from one unit to another (Cohen et al., 1980). An example is the coronary care facility where the relevant service units are coronary care, post-coronary care, intensive care, medical care, surgical and ambulatory. Cohen (1980, p.113-119) and Weiss et al. (1982) have developed a testing

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[3]It must be remarked that AUTOGRP has allowed to define diagnosis-related groups . In other words, the development of the diagnosis-related groups has been initiated by a need for development of a planning system which is fundamentally a hospital service requirements planning system. The specificity of AUTOGRP is discussed in a later section.

[4] A semi-Markov process is similar to Markov chains. A Markov chain is a specific stochastic process or a sequence of a random variable Xt proceeding through time. A Markov chain is a memoryless stochastic process, i.e. the probability of moving from one state to another depends only upon the state that the patient currently is in and not on any further past information. In a semi-Markov process, the assumption is made that the time spent in anyone state, given that the patient will be transferred to another is a random variable (Weiss, 1980). These processes are therefore specified by the transition probabilities among locations and the parameters of the particular length of stay distribution for each possible transfer (Weiss et al., 1982).

procedure to find out whether transitions are Markovian. Interesting in the study of Weiss (1980) and Cohen et al. (1980) is that they develop a simulation model of patient flows in a progressive patient care facility with finite capacities. The simulation is based on a semi-Markov process model that is applicable to the case of infinite capacity. This allows to 'fold' patient movement in a compact form through the use of a transition probability matrix [5]. The simulation model is used "to generate patient flows under various capacity configurations and rules for dealing with blocked transfers" (Cohen et al., 1980). A blocked transfer occurs when the appropriate unit for subsequent transfer is at full capacity. These studies show that alterations in the capacity level of one unit has second-order effects on the performance of other units.

Finally, Kumar et al. (1993) found that there is an important relationship between the organisational structure of a hospital and the performance of systems which schedule patients for ancillary services. This means that one must be careful to generalise the results obtained for one hospital.

The previous literature review give the following lessons:

1. A hospital can be described as a network of service units with finite capacity through which patients are flowing.
2. There are relationships between the capacity of different (service) units and balancing of the workload is only possible when these relationships (the so-called capacity structure) are taken into account.
3. Hospital service requirements planning requires a study of the resource consumption of the patients flows

[5] A transition probability matrix is a matrix showing the relative frequencies (or the probability) that a patient residing in a certain state at time t makes the transition from this state to another state at time t+1.

1.4. Motivations for doing this research study

1.4.1. Growing external pressures to operate in an efficient way

Hospitals are under a growing pressure to contain costs and to improve quality of care (Decoster, 1993). Government continuously change payment systems in such a way that hospital managers face an increasing financial risk (Herck et al., 1993; Decoster , 1994). Financing systems evolve from retrospective cost reimbursement systems (whatever the level of costs) to prospective budgeting systems (Decoster, 1994). In a budgeting system, the importance of hospital activity indicators and operational performance measures increases (Delesie, 1991; ...). Examples of such measures are length of stay and occupancy. Competition between hospitals introduces an increasing attention for patient service, clinical and medical quality and waiting times (Evers et al., 1993). Finally, the patients are becoming more and more aware of their position and rights as customers of health care (Macstravic, 1988) and hospitals do not seem to be patient-focused, at least according to some consultants (Lathrop, 1993).

The above external pressures cause a search for efficiency in health service delivery (OECD, 1990; Business Week, 1994). In the beginning the efficiency efforts have been focused on administrative and financial controls (Rosenstein, 1991). This kind of efforts did not produce the expected improvements in performance (Rosenstein, 1991). It has become clear that the complexity of the hospital organisation and the lack of integration in the operations has been one of the main barriers for more efficiency in the health service delivery.

1.4.2. The complexity of the hospital organisation and the lack of integration

Figure 1.2 shows the organisation of a typical, large acute care hospital. Patients are residing in small, specialised patient units supported by multiple ancillary and support departments (Lathrop et al., 1991). Furthermore the hospital is described as a complex organisation of a network of relationships between mainly professional groups and between these groups and the environment (Defever, 1982, p.65). Such a hospital organisation involves "multiple agents who have partial information, disparate (local) goals and limited communication capabilities" (Kumar et al., 1993). According to Galbraith (1973), there are two possible strategies to better co-ordinate the activities in such a complex organisation: (a) reduce the need for information processing or (b) increase the capacity to process more information.

The first strategy of reducing the need for information processing has been strongly emphasised in the so-called patient-focused hospital idea which has been promoted by several American consultants (Lathrop et al., 1991). The basic idea of patient-focused hospital is that there is something wrong with the operating structure of the hospital and that the health service delivery needs to be restructured in such a way that it is centred around the patient. This involves creating more or less autonomous departments which are treating resource-homogeneous patient groups; redeploying resources to such departments and cross-training of personnel (Lathrop, 1993).

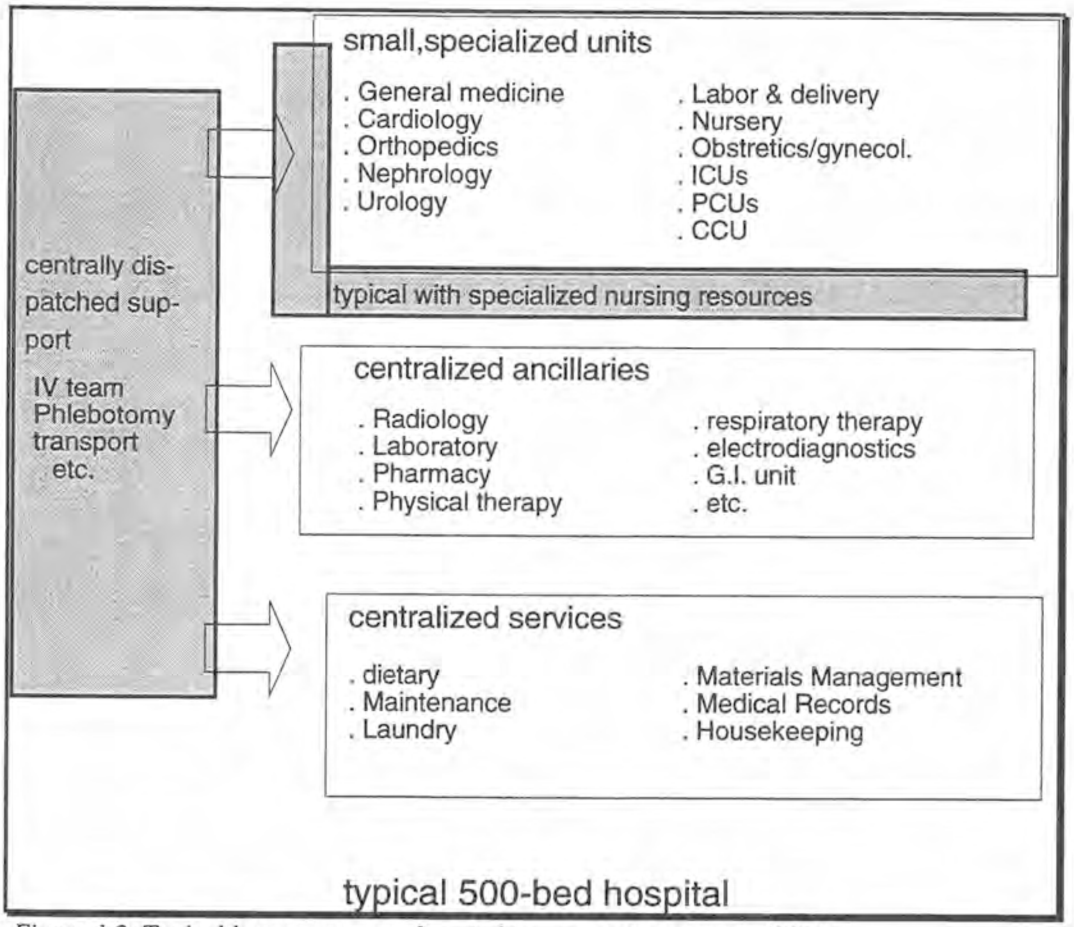

Figure 1.2. Typical large acute care hospital (source:Lahtrop et al., 1991)

One of the main objectives is to reduce the need for information processing.

The development of more integrated information systems is a second approach to promote integration in a complex organisation. Kumar et al. (1993) find that the greatest benefits of integrated scheduling of ancillary services are realised when the personnel of the ancillary services do not consider their intermediate production (e.g. laboratory test) as their final output, but when the patient is placed central. In other words, accepting integration assumes a patient-focused hospital where for instance the smooth throughput of patients is more important than the high utilisation of facilities. It is the approach of integrated information systems which is used in this study, with the limitation that we are only interested in those information systems which support capacity management decisions.

1.4.3. Growing interest for integrated capacity management

In order to learn more about capacity management in hospitals, we have done a preliminary study in three American hospitals. Appendix 1 shows these three different hospitals and the name and the position of persons which have been interviewed. For the interviews, we have used a semi-structured survey covering such topics as admission scheduling, surgical scheduling, nursing staffing, patient-focused care, the role of information systems in resource management and the link between financial services and resource management. In appendix 2 we reproduce a report which has been made as a result of these interviews. The conclusions in this report (which have been discussed with the CEO of the hospital) are in general typical for the findings in the other hospitals.

We found a very unstable pattern of daily admissions in the hospitals. In the report in appendix 2, several figures show the evolution of the daily number of admissions in one of the case hospitals. Besides the seasonal pattern, one observes the daily variability in this pattern. The cause of this variability is the common practice of physicians to schedule themselves the admission date of their patients. The resulting problem is that this variability causes unstable workload patterns and unstable occupancy rates of the departments. A first step in solving the problem is the application of a centralised admission scheduling system, but it has been recognised that most of those systems all focus on maximising the utilisation of bed resources, " which can lead to extreme variations in the utilisation of other resources " (Smith-Daniels et al., 1988, p.899). For instance the nursing department in one of the case hospitals perceived itself as being the unit that is the most affected by the high variation in daily census. This results in a need for extreme flexibility even to the point that nurses must be able to adjust on a shift by shift basis. Mechanisms currently used in the hospital to obtain such flexibility are built-in incentives for the nurses to work overtime and during the weekend, on-call staff, floating nurses between nursing units and hiring outside nurses. Nonetheless, it is unusual (in practice as well as in theory) to develop and implement scheduling systems which take into account the nursing workload. These observations are confirmed by the study of Siferd et al. (1992) on hospital nursing workforce staffing and scheduling.

One important conclusion of these preliminary studies is that the dependency relationship between the different capacity resources in a hospital is insufficiently considered in the management of the capacity of these resources. The demand for hospital services must be treated "in terms of all of the resource requirements associated with a given product [patient] with the objective of balancing the utilisation of work-force and facilities resources" (Smith-Daniels et al., 1988, p912). This conclusion is further supported by the doctoral study of Vissers where he performed several case-studies in Dutch hospitals (Vissers, 1994):

> *"Inpatient capacity management concentrates on the relationship between admission planning (the inflow of patients) and the use of inpatient resources such as beds,*

operating theatres and nursing staff. There are two ways to obtain a balance: by improving admission planning taking into account resource impacts when admitting patients, or by improving the allocation of resources" (Vissers, 1994, pp. 203).

The same idea can be found in the review article of Smith-Daniels et al. (1988).

The main focus in this study is on admission scheduling taking into account the impacts for several resources. We call such an approach service requirements planning. The fundamental condition to link admission and resource uses is the categorisation of patients in resource-homogeneous groups (see also Vissers, 1994, p.205).

1.4.4. The development of a product definition for hospitals

In their 1988 review article on capacity management in hospitals, Smith-Daniels et al. acknowledge the opportunities for research on integrated hospital service requirements planning in a product-line environment. Planning resources for patients at the moment of admission scheduling requires knowledge about the expected resource use. This is only possible when the patient is identified as a certain product, i.e. classified in a certain category. In the past, the main barrier for an operations management view on the hospital process was the absence of a clear understanding of 'what constitutes a product of a hospital' (Van Dierdonck et al., 1992). The introduction and diffusion of a patient classification system called 'Diagnosis-related Groups' (DRGs) brought a general accepted way of describing the output of a hospital (Fetter et al., 1985; Fetter et al., 1986; Fetter, 1991). This was the start of a new wave of research on better ways to manage resources within hospitals (Van Dierdonck et al., 1991).

1.4.5. The natural outcome of research going on for years

In 1988 an article was published developing a conceptual framework for hospital service requirements planning (Rhyne et al., 1988). The particularity of the proposed framework is that it uses concepts borrowed from the information technology of Manufacturing Resources Planning (MRP II). Roth and Van Dierdonck (1992) further elaborate the conceptual framework and introduce some fundamental research questions concerning hospital service requirements planning in hospitals while using MRP and DRG concepts.

In this study, we deal with a subset of the research questions presented by Roth et al. (1992). We mainly focus on different sources of uncertainty which are typically found in a hospital environment and we study the impact of these uncertainties on the performance of the Hospital Service Requirements Planning System (HSRP) as proposed by Roth et al. (1992).

2. PROBLEM ANALYSIS

In this study, we envision the development of a hospital service requirements planning system which allows the matching of the demand and the capacity of several resources in an acute care hospital. The design characteristics of the planning system are as follows:

(1) The system focuses on patient flows and Diagnosis-related groups are used to describe the patient flows.

(2) The system recognises dependencies between hospital resources and tries to balance the capacity of several resources taking into account the service requirements generated by the patient flow. The system requires a description of the capacity structure of the hospital.

(3) The planning system requires the input of case-based resource management data.

(4) The planning uses concepts which are transferred from the manufacturing planning and control theory.

In the following paragraphs, we develop the design characteristics of the HSRP system. In a final section, we discuss the measurement of the performance in this study.

2.1. Patient flows and diagnosis-related groups

2.1.1. What are Diagnosis-related Groups (DRGs) ?

As pointed out earlier, the DRGs are a patient classification system which has originated out of a search for more resource homogeneous patient classification (Valinsky, 1974). The Diagnosis Related Groups (DRGs) were developed at the Yale School for Management (Fetter et al., 1980, 1984, 1985, 1986, 1991, 1991 (eds.); Mullin 1983, 1985). Originally, it was meant as a tool for hospital management, planning, utilisation review and the like. Later the DRGs were adopted by the federal US. government as a basic structure for hospital prospective reimbursement (Fetter, 1991 (eds.)).

The DRG patient classification system represents a manageable number of groups of patients who are similar in terms of pathology and the processing of care, and who have a similar pattern of resource intensity.

The DRG is a patient classification system. This means that N patients are taken and grouped into K case types, where K < N, so that the patients within each group are more alike (homogeneous) than cases from different groups, according to the classification criteria

(Hornbrook, 1982a). Because the DRGs cover the entire range of patients seen in an inpatient setting, they provide a tool for measuring the case-mix of an inpatient hospital (Averill, 1991).

Patient Classification Systems provide a means of measuring the case-mix of a hospital (Averill, 1991). Case-mix refers to the variety of clinical conditions being treated by one or more providers of care (Lichtig, 1986). It is over twenty years since Feldstein's original studies developed simple measures of case-mix and demonstrated the important cost implications (Spiegel, 1986; Bardsley et al., 1987). Since then, many authors confirmed that case-mix is a major determinant of hospital cost and resource use (Thompson et al., 1975; Olowokure, 1978; Klastorin et al., 1980;....; Closon, 1991).

For a specific hospital, an appropriate DRG is assigned to each patient using discharge abstract data and DRG grouper software (Lichtig, 1986, p.117). The data items needed for assigning DRGs are (Fetter, eds., 1991): principal diagnosis, secondary diagnosis, significant operating procedures, age, sex and discharge disposition. All diagnoses must be coded using ICD-9-CM (International Classification of Diseases, Ninth Revision, Clinical Modification). The ICD-9-CM provides over 13000 codes for identifying and describing diseases and disorders (injuries, impairments, symptoms and causes of death) that can serve as a patient's principal diagnosis. They are classified by medical specialities or organ system involvement (see Hornbrook, 1982; Lichtig, 1986 and Fetter, 1991). The ICD-9-CM also provide ±3000 codes for diagnostic and therapeutic procedures (Mullin, 1985; Lichtig, 1986). Appendix 3 shows the categories of the ICD-9-CM diagnosis codes and ICD-9-CM procedure codes.

The DRG grouper generally works as follows (Lichtig, 1986, p.108; Fetter, 1991a):

1. Based on the ICD-9-CM diagnosis codes, a patient can be assigned to one of the 23 Major Diagnostic Categories (MDC). The 23 MDCs are a classification of the ICD-9-CM codes in terms of an organ or functional system, congruent with the organisation of medical specialities. Appendix 4 shows these 23 Major Diagnostic Categories.

2. Once a patient is assigned to a MDC, tree diagrams can be used to find the final DRG to which the patient belongs. Figure 2.1. shows a general structure of such a tree-diagram. Appendix 5 shows the tree diagram of the MDC 5, diseases and disorders of the circulatory system. In most MDCs, the first question is whether a surgical (OR) procedure is performed. If a surgical procedure can be identified, the patient assignment procedure follows the surgical branch of the tree. Otherwise it follows the 'medical' branch.

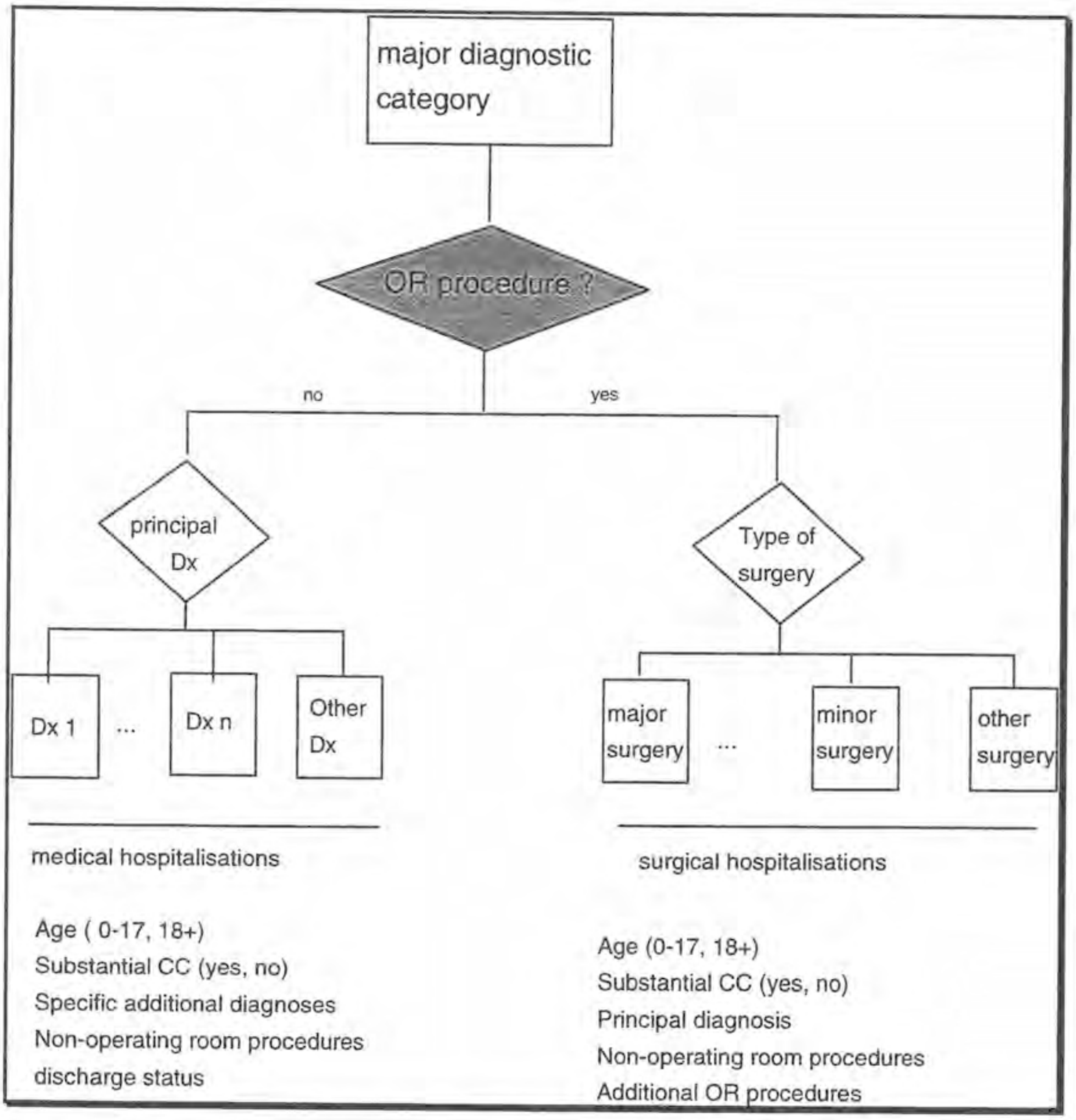

Figure 2.1. Structure of DRG classification within Major Diagnostic Categories

3. For patients who had an OR procedure, the next decision is based on the specific type of the procedure. The procedures are organised according to a hierarchy , based on medical severity. Patients with more than one OR procedure are placed into the category highest in the hierarchy. Further decisions of procedure categories are based on patient age, presence of complications or comorbidities, specific diagnosis or any other information clinically relevant to the procedure.

4. A patient without operating room procedure is assigned to a category based on the principal diagnosis. Further classification is based on patient age, presence of complications or comorbidities, use of non-operating room procedures or any other information clinically relevant to the category.

As an example, figure 2.3. shows a part of the tree diagram in appendix 5. If one were to assign a DRG manually, the process would follow steps similar to these:

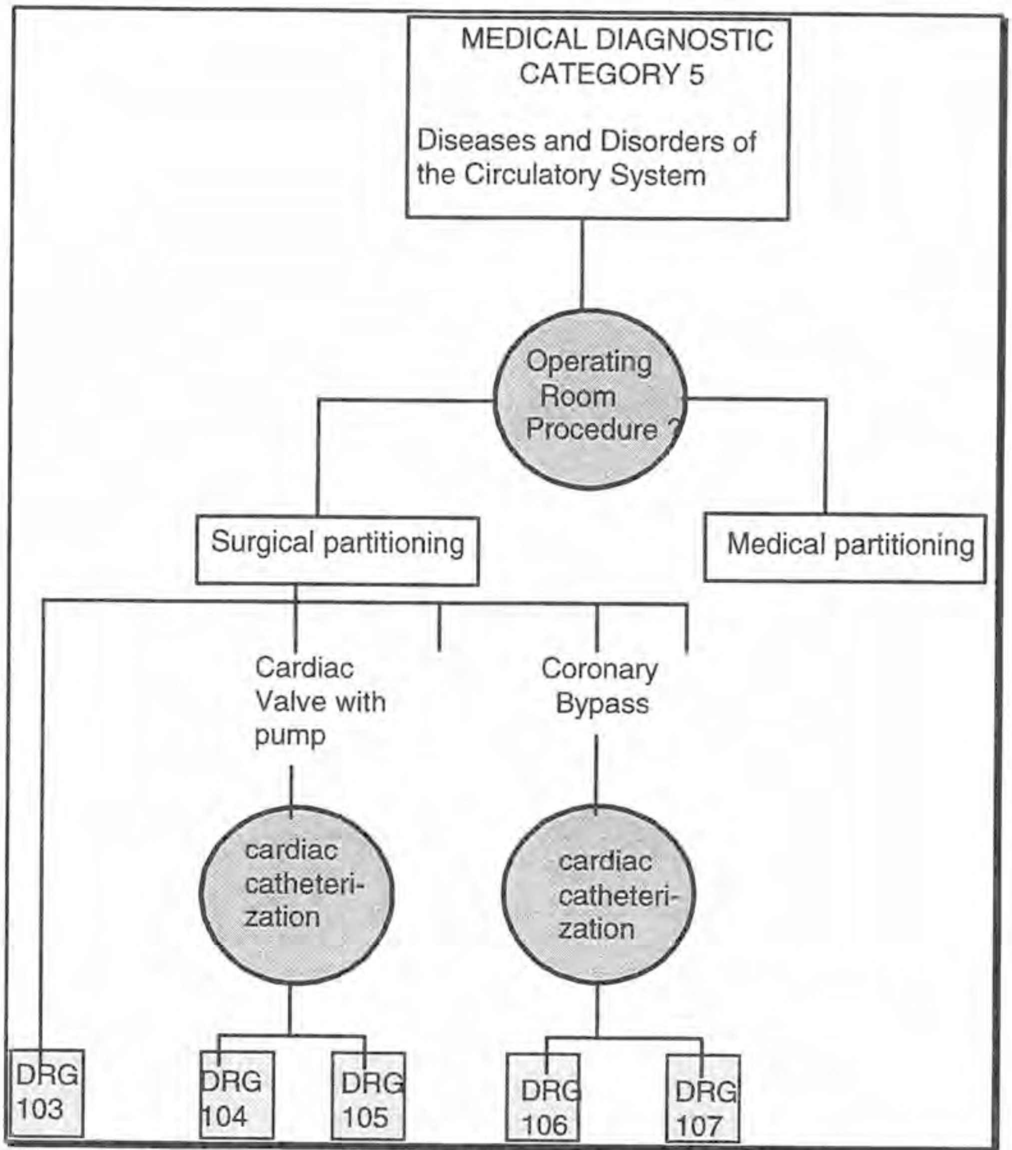

Figure 2.2. A part of the structure of the DRG classification within MDC 5

1. First, identify the MDC in which the case belongs based on the principal diagnosis. For a principal diagnosis related to the circulatory system, the case belongs to MDC 5 (which is shown in appendix 5).

2. If an operating room (OR) procedure is indicated on the record, then the case falls into a DRG belonging to the surgical partitioning of the tree diagram.

3. If the OR procedure is a heart transplant, then the case belongs in DRG 103, and the process is complete.

4. However, if the OR procedure is not a heart transplant, but is a cardiac valve procedure with pump, then the case belongs to one of two DRGs: DRG 104 or DRG 105.

5. If cardiac catheterisation has been performed, then the case belongs to DRG 104. If this is not the case, the case belongs to DRG 105.

6. If the OR procedure is a coronary bypass, then the patients belongs to DRG 106 or DRG 107 depending on whether or not cardiac catheterisation has been performed.

7. If no OR procedure is indicated on the record, then the case falls into a DRG belonging to the medical partitioning of the tree diagram. The further assignment of patients to DRGs occurs in a similar way as in the surgical part.

The tree diagrams mentioned in the second step are established using a combination of clinical judgement and a program called AUTOGRP. AUTOGRP distinguishes between groups based on the greatest reduction in a dependent variable (in the early versions length of stay; in later versions charges) through the introduction of additional independent variables (Mills et al., 1976).[6] The statistical procedure worked as follows: many variables (such as age, sex,...) were used to sort patient records ('branching') into groups displaying similar values of a selected dependent variable such as length of stay. At each stage the process selects the most influential variable which will split the data into groups which differ on length of stay. To ensure that groups were also clinically consistent, AUTOGRP allows intervention and approval at each stage of branching.

The Diagnosis-related Groups were adopted in 1983 by the Health Care Financing Administration (HCFA) for prospective hospital payment for Medicare beneficiaries (i.e. primarily the over age 65 population)(Averill, 1994). Since then, these HCFA DRGs have been regularly modified. McGuire (1991) describes this evolution. Currently, the HCFA DRGs version 10.0 has been issued (Averill, 1994). The second and third column in Table 2.1. show the major changes between the version 2.0 (1984) and version 10.0 (1992). Some new DRGs and MDCs are created, but the major change is the inclusion of CC subclasses (CC = comorbidities and complications) in the classification.

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[6]. The statistical approach used by AUTOGRP is very similar to the Automatic Interaction Detector approach developed by Sonquist and Morgan (see McMahon, 1987).

Table 2.1. Different DRG versions and their characteristics

	HCFA DRGs version 2.0	HCFA DRGs version 10.0	AP-DRGs version 10.0	RDRGs	APR-DRGs version 10.0
Number of DRGS	470	487	617	1142	1437
Tracheotomy DRG	No	Yes	Yes	Yes	Yes
Transplant DRGs	No	Yes	Yes	Yes	Yes
Multiple Trauma MDC	No	Partial	Yes	Partial	Yes
HIV Infection MDC	No	Partial	Yes	Partial	Yes
Newborn birthweight used	No	No	Yes	Partial	Yes
NACHRI [7]Paediatric Changes	No	No	Yes	No	Yes
Major (Extreme) CCs[8]	No	No	Yes	Yes	Yes
Death used in Definition	No	Yes	Yes	Yes	Yes
CC list Re-evaluated	No	No	Partial	No	Yes
Non-OR CC modifier	No	No	Yes	No	Yes
Age CC Modifier	No	No	No	No	Yes
Multiple CCs Recognised	No	No	No	No	Yes
CC subclasses	0	2	2	3 à 4	4
Central Source for Updates	HCFA	HCFA	3MHIS	No	3M HIS
Official Definitions Manual	Yes	Yes	Yes	No	Yes
Base DRGs used	-	-	-	HCFA	AP-DRGs

The major critic on the basic DRG system was that it did not adequately account for the severity of a patient's illness, and more particularly for comorbidities and complications which are considered as important determinants of resource use (Rosko, 1988). As a reaction to this critic, the Health Systems Management Group of Yale developed the so-called 'refined DRGs' or RDRGs(Health Systems Management Group, 1985; Freeman, 1991). The main objective of this refinement was to revise the use of complications and comorbidities (CC) in the DRGs. In this refined model, after some patients are isolated (temporary tracheotomy, early death), other medical (surgical) patients are placed in Adjacent DRGs (ADRGs)according to their principal diagnosis (surgical procedure). For each ADRG, patients are defined as final DRGs based on the impact of the secondary diagnosis on resource use (e.g. cc with major, moderate, minor or no effect on resource use; see figure 2.3.). This classification resulted in 1142 categories (see fifth column in table 2.1.)

[7] NACHRI = National Association of Children's Hospitals and Related Institutions. They performed mid 1980's extensive research on alternative approaches to reformulating the DRG categories for neonates and other pediatric patients.

[8] CC = Complications and Comorbidities.

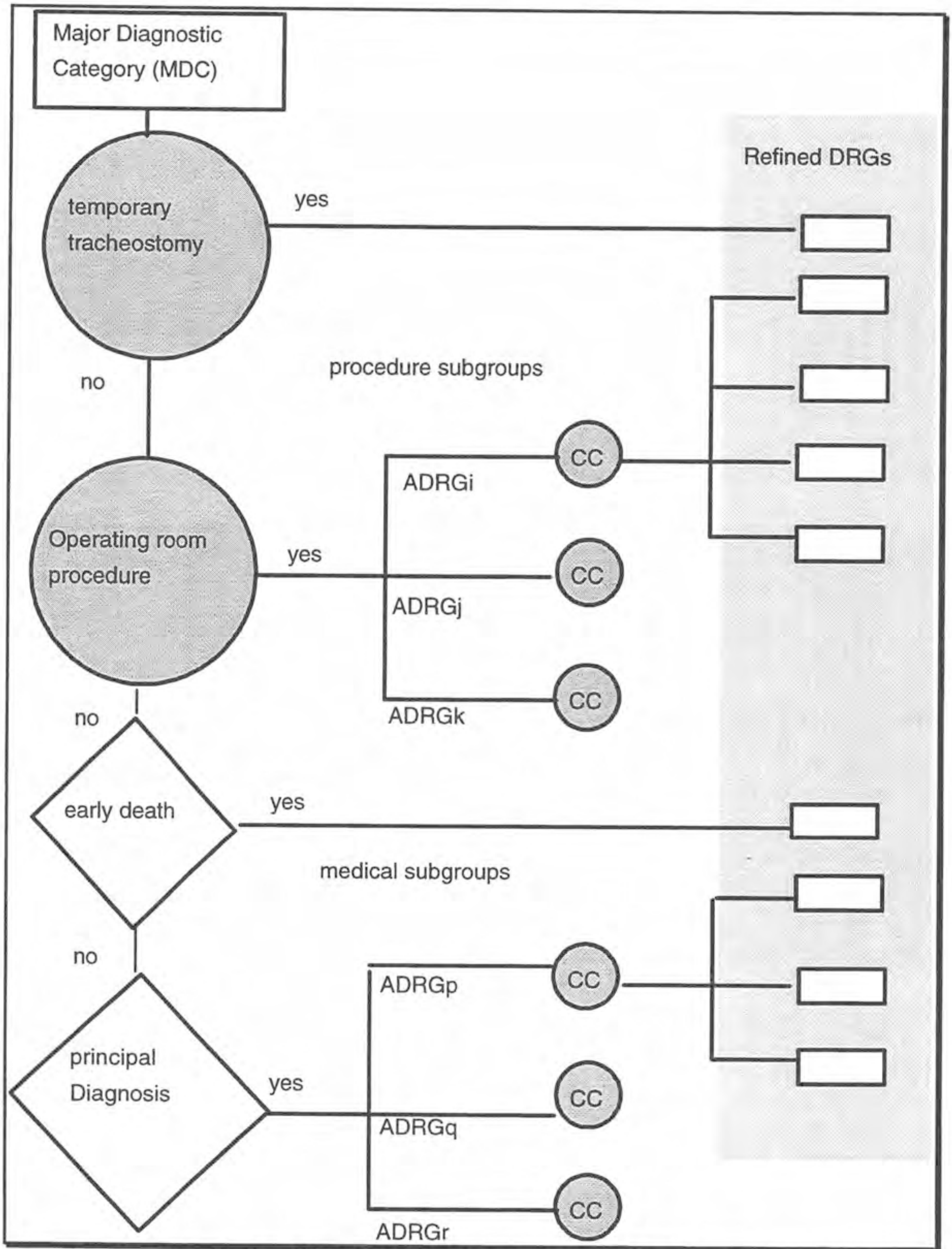

Figure 2.3. General structure of the Refined DRGs (RDRGs) (Fetter, 1991, p.72).

The New York State Department of Health entered into an agreement with 3M Health Information Systems (3M HIS) to assist with the evaluation of the need for additional DRG modifications (Averill, 1994a, p.76 and 1994b). The DRG definitions developed by the New York State and 3M HIS are referred to as the All Patient DRGs (AP-DRGs).The AP-DRGs introduced many changes to the HCFA DRGs (see table 2.1.). The most important change is the departure from the use of principal diagnosis as the initial variable in DRG assignment. For instance when the age of the patient at admission is less than 29 days, the AP-DRGs assign a patient to the neonatal MDC regardless of the principal diagnosis of the patient (Averill, 1994). Some of the DRG modifications originally developed in the AP-DRGs have subsequently been adopted in the HCFA DRGs.

Based on the research on the refined DRGs and on the All Patient DRGs, the All Patient Refined DRGs (APR-DRGs) are developed. The APR-DRGs include four severity subclasses within each AP-DRG. The assignment of a patient to one of these four severity subclasses takes into consideration not only the severity level of the secondary diagnoses but also the interaction between secondary diagnoses, age, principal diagnosis and the presence of certain non-operating room (OR) procedures (Averill, 1994). The presence of multiple diagnoses is a characteristic of high severity patients (Averill, 1994). There are 1437 APR-DRGs. According to Averill (1994), the APR-DRGs consistently show the best statistical performance in terms of R^2.

Many different studies have been made evaluating the (comparative) performance of these different DRG systems. In Belgium, we have to refer to the work of Closon (1991). In this comprehensive study, Closon (1991) clearly shows that RDRGs are more homogeneous than the basic HCFA DRGs, but on an individual hospital level there is the problem of having not enough cases within each category as a consequence of the multiplication of the number of categories in the RDRGs (Closon, 1991, p.232). Another conclusion in this study is that the New York DRGs (a predecessor of the AP-DRGs) could apparently not improve the explication of the utilisation of resources in a significant manner, certainly not in terms of length of stay (Closon, 1991, p.284).

2.1.2. Why using DRGs in this study ?

The Diagnosis-related Groups are not the only patient classification system which has been developed during the last decade. Besides DRGs several other patient classification systems have been developed. In this section we give some motivations for using DRGs in HSRP. In the next paragraphs, we first develop a framework to compare patient classification systems. Thereafter we explain why we have chosen the DRG system.

2.1.2.1. A framework for comparing patient classification systems

Different authors have developed performance criteria to evaluate patient classification systems (Wood et al., 1981; Hornbrook, 1982b; Jencks et al., 1984; Health Systems Management Group, 1985; Rosko, 1988). In summary, these performance criteria are validity (internal and external), practicality, reliability and acceptability.

In evaluating the validity of a patient classification system, it is important that it is conceptually well founded (Jencks et al., 1984), i.e. it must be meaningful in view of the purpose of the study (Wood et al., 1981), or it must contain those dimensions which are relevant for the study purpose (Hornbrook, 1982b). In terms of Wood et al. (1981), our study demands a case-mix measure that is economic and administrative meaningful. This means, that within case types, the vectors of amounts of the various goods and services needed for the patient's clinical management must be homogeneous. For example, within a case type, the patients should be homogeneous as to the patient days on each unit of the hospital and to the nursing hours (Wood et al., 1981). This can be translated as homogeneity in resource intensity (Averill, 1991). Many authors indicate that homogeneity in resource consumption cannot be reached without taking the severity of illness into consideration (Horn et al., 1983; Health Systems Management Group, 1985; McMahon, 1987; Rosko, 1988; Sharkey et al., 1991). Furthermore, taking into account the severity of illness will enhance the medical meaningfulness (Wood et al., 1981). Medical meaningfulness is again important for the acceptability of the system by physicians.
Another factor causing heterogeneity in resource consumption is the variation in medical and physician practice style (Wickings, 1987; Fellowship Training Program, 1991; Feinglass et al., 1991). For instance, physicians who undertake a particular operation infrequently may complete it more slowly (Wickings, 1987). One way to reduce variation in practice style is to develop and implement clinical practice guidelines (see further).

Another aspect of validity is the way in which the dimensions are operationalised (Hornbrook, 1982a). For our purpose, a patient classification system that lists the vector of amounts of services delivered or resources used is preferable above a system that summarises resource consumption in one indicator.

It has to be proved that a case-mix measure developed in the US. can be used in European countries. We call this external validity of a case-mix measure. Many European countries, for instance, are not using the ICD-9-CM coding system (Casas, 1991). Conversion of the local coding system to ICD-9-CM is needed when these countries want to use particular patient classification systems based on this coding system (Reid, 1991). One conclusion of a Dutch study is that *"it is not easy to use the American DRG definitions without modification in the Netherlands because the medical and/or statistical homogeneity for a number of DRG's is not quite satisfactory"* (Verheyen et al., 1992).

A valid patient classification system must be balanced against practicality considerations. This chiefly concerns cost-effectiveness (Wood et al., 1981; Hornbrook, 1982a) and the flexibility of using the measure for multiple purposes (Hornbrook, 1982a).

Several authors have identified some general problems of reliability with case-mix measures (Wood et al., 1981; Hornbrook, 1982a; Mullin, 1985, Rosko, 1988; Iezzoni, 1990). Reliability means that the repeated applications of the measure in the same environment must provide the same or similar results. Since most patient classification systems use a computerised algorithm to classify patients, the primary threats to reliability are observer errors by physicians who may assign an incorrect diagnosis to a case, classification errors by medical technicians who may assign an incorrect code to a case and processing errors (i.e. accidentally inputting the wrong codes)(Rosko, 1988). Some procedures to improve the reliability have also been proposed. One of these procedures is making the medical decision making process more explicit. Because standardisation is very important to get resource and service homogeneous case types, we want to emphasise that an important feature of reliability in this study is that the clinical and hospital processes are increasingly standardised (Fellowship Training Program, 1991). Some current evolutions are bringing forward more standardisation in the health service delivery process. Clinical guidelines (National Quality of Care Forum, 1993) [9] and clinical pathways (Zander, 1992)[10] are increasingly developed by hospitals in order to reduce variation in health service delivery. This will be further supported by the many different continuous improvement projects going on in hospitals (Shortell, 1995). One of the essential elements of total quality management efforts is to continuously increase knowledge of and control over variation in the processes of work (Berwick, 1991). It is this kind of standardisation which will also have a positive influence on the reliability of the patient classification system.

Finally, to be acceptable for capacity planning purposes, the patient classification scheme must contain a manageable number of categories (Fetter, eds., 1991). This can only be attained by making a lot of trade-offs: the trade-off between clinical homogeneity (tending to a large number of categories) and resource homogeneity (tending to a few number of categories)(Wood et al., 1981); trade-off between the additional explanatory power and the increased costs of maintaining a larger number of categories (Burik et al., 1981). It is a search for a balance (Wood et al., 1981) with the aim of defining sufficient categories to be clinical acceptable but not too much categories to avoid that stable patterns in case-types cannot be detected. Of course it must be determined how many categories are really used in the hospital. For instance, Closon (1991) finds that 15 DRGs represent 45% of the total number of patients admitted.

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[9] Clinical (practice) guidelines are a means of providing knowledge, derived from a scientific analysis of the practice of medicine, in a useful format to physicians, patients and others about the best use of health care resources. (Nash, 1993)

[10]. Clinical pathways or critical pathways are a clinical management tool that organizes, sequences, and times the major interventions of nursing staff, physician, and other departments for a particular case type subset or condition. (Zander, 1992).

2.1.2.2. Comparing alternative patient classification systems

We completely agree with Delesie (1991) that it is better to develop new management tools using existing patient classification systems than to develop new specific purpose patient classification systems. That is why we have made an in-depth study of the usefulness of the existing patient classification systems for service requirements planning.

Besides DRGs, the most frequently mentioned other patient classification systems are Patient Management Categories (PMCs)(Young et al., 1982), Disease Staging (Gonella et al., 1984), Severity of Illness Index (SII)(Horn, 1983) and the Computerised Severity Index (CSI) (Sharkey et al., 1991). Excluded from the analysis are classification systems that are either limited to a subset of patients (e.g. APACHE [11]) or those for which rigorous empirical assessments have not been published (e.g. MEDISGRPS[12])(Rosko, 1988).

Table 2.2. Disease Staging, Patient Management Categories and Severity of Illness Index: their purpose, development procedure and use.[13]

DISEASE STAGING

REFERENCES: Gonella J.S, Hornbrook and Louis, 1984.

PURPOSE

Providing a more complete specification of the patient's illness so that any application requiring a case-mix measure will not confound differences in patient's condition with differences in the therapeutic processes.

DEVELOPMENT

The Disease staging protocol defines progressive levels of clinical severity, corresponding to the biological progression and complications of the disease. In general, the four stages of disease can be described in ascending order of severity as: No disease present, or diagnosis unknown (stage 0); conditions with no complications or problems of minimal severity (local or systemic)(stage 1); problems related to an organ or organ system with increased probability of complications (stage 2); generalised systemic involvement, multiple site involvement; poor prognosis (stage 3); death or most severe stage possible (stage 4)

A panel of 23 medical consultants drawn from eleven medical school faculties assisted in the specification of the disease staging criteria for the 420 medical conditions. Each disease was assigned to two members of the panel who developed staging criteria independently. The panel chairmen and originator of the disease staging approach, J.Gonnella, then reviewed each set of stages. Any differences between the independent sets of criteria were discussed to reach a consensus among the three physicians.

USE

Available computer software will classify patients into any of 420 diagnostic categories, which contain about 90% of all admissions to short-term general hospitals, and assign an ordinal stage within each category. With few exceptions, diseases are staged on the basis of principal diagnosis, secondary diagnosis, and discharge status.

[11] APACHE = Acute Physiology and Chronic Health Evaluation is mainly applied to intensive care (for a review see Thomas et al.,1991).

[12] MEDISGRPS = Medical Illness Severity Grouping (Brewster et al., 1985).

[13] The patient classification systems are here described as they are originally developed. Since then changes have occurred.

PATIENT MANAGEMENT CATEGORIES (= PMC)
REFERENCE: Young et al.1982.

PURPOSE
Identifying and incorporating clinical and severity distinctions among patient types where those distinctions reflect expected differences in patient management and, consequently, hospital resource requirements.

DEVELOPMENT
50 disease specific panels, composed of specialist and generalist physicians developed approximately 800 PMCs through a three step procedure:

1. Clinically homogeneous patient categories are defined by physicians on the basis of the final diagnosis and reason for admission to the hospital.
2. Physicians specify patient management paths (PMPs) or management strategies (key services that are expected to be provided) which describe the essential components of the diagnostic and treatment regimen for each patient category.
3. The vector of services is converted into a scalar resource value via the assignment of dollar costs to each component.

USE
The PMCs have been automated for use on discharge abstracts (mapping ICD-9-CM codes and other data elements contained on the discharge abstract onto the PMCs), so that each patient can be classified into a PMC without collecting new data on reason for admission.

SEVERITY OF ILLNESS INDEX (=SII) and COMPUTERIZED SEVERITY OF ILLNESS INDEX (CSI)
REFERENCES: Horn, Sharkey, Bertram, 1983; Sharkey et al., 1991.

PURPOSE
Measuring the severity of the patient's illness, so that the performance of physicians with respect to prescribing appropriate lengths of stay can be examined and the overall costliness of the hospital can be predicted.

DEVELOPMENT
The SII is an ordinal measure of patient severity consisting of four levels. The assessment of severity depends upon the disease specific scores (from 1 to 5) for seven variables: stage of the principal diagnosis, complications of the principal diagnosis, concurrent interacting conditions that affect the hospital episode of treatment, patient dependency on the hospital facilities and staff, extent of non operating room life support procedures, rate of response to therapy or rate of recovery, impairment remaining after therapy for the acute aspect of the hospitalisation.

USE
Using the seven dimensions, experienced raters evaluate data in the medical record, and score the patient at one of four levels of severity for each of the seven variables. The overall SII (taking into account the interaction of the diseases) value is determined by assessing the pattern of the seven dimensions ('implicit or subjective integration into an overall score from one to four').

In response to concerns about the SII (reliability and validity), the Computerised Severity Index (CSI) has been developed. The CSI uses information based on laboratory values, vital signs, radiological findings, and other clinical information, such as those used by clinicians to determine the existence of diagnoses for patients and by nurses to assess a patient's need for nursing care. This information is found in the medical record but not summarised in current discharge abstract forms. In this system a sixth digit reflecting severity of illness is added to the five digit ICD-9-CM code, reflecting increasing severity from levels one to four.

In fact there are two different ways to classify patients: an indirect method using factor analysis and cluster analysis to estimate the case-mix of a hospital and a more direct method using clinical decisions or a combination of clinical decisions and statistical methods (Williams et al., 1984).

Several authors have made an extensive review of the patient classification systems (Hornbrook, 1982a and 1982b; Rosko, 1988; Thomas et al., 1991).

Internal validity

After careful review of the previous mentioned studies, two of the four patient classification systems do not fit the purpose of this study, i.e. Disease Staging and SII (CSI). Disease staging seems to be an appropriate patient classification system to assess timeliness of hospital admissions but not to predict resource requirements because it does not depend on actual and expected utilisation patterns (Taroni, 1994). The Severity of illness and the CSI measures are advocated as a refinement to the DRG system and not as a stand-alone patient classification system (Sharkey et al., 1993). In the rest of the comparison, we only focus on DRGs and PMCs.

An important distinction between PMCs and DRGs is that the classification of patients in PMCs is affected by their expected resource utilisation pattern while the DRG classification is based on the services actually provided (Hornbrook, 1982b). Moreover for each PMC a patient management path specifying the required services is defined. Figure 2.4. shows an example of such a patient management path. DRGs do not specify such a vector of services. Patients within one DRG are assumed to be homogeneous in terms of length of stay or charges where both are proxy measures for resource consumption (Coles, 1987)

For the purpose of service requirements planning, the PMC system is more valid (conceptual stronger) because it defines standardised patient management paths with a specification of the expected essential components of the diagnostic and treatment regimen for each patient category. Furthermore, PMCs were designed to measure both severity and resource intensity [14] (Charbonneau et al., 1988) while DRGs were designed to relate a hospital's case mix to its resource intensity only (Averill, 1991).

[14] Resource intensity refers to the relative volume and types of diagnostic, therapeutic, and bed services used in the management of a particular illness.

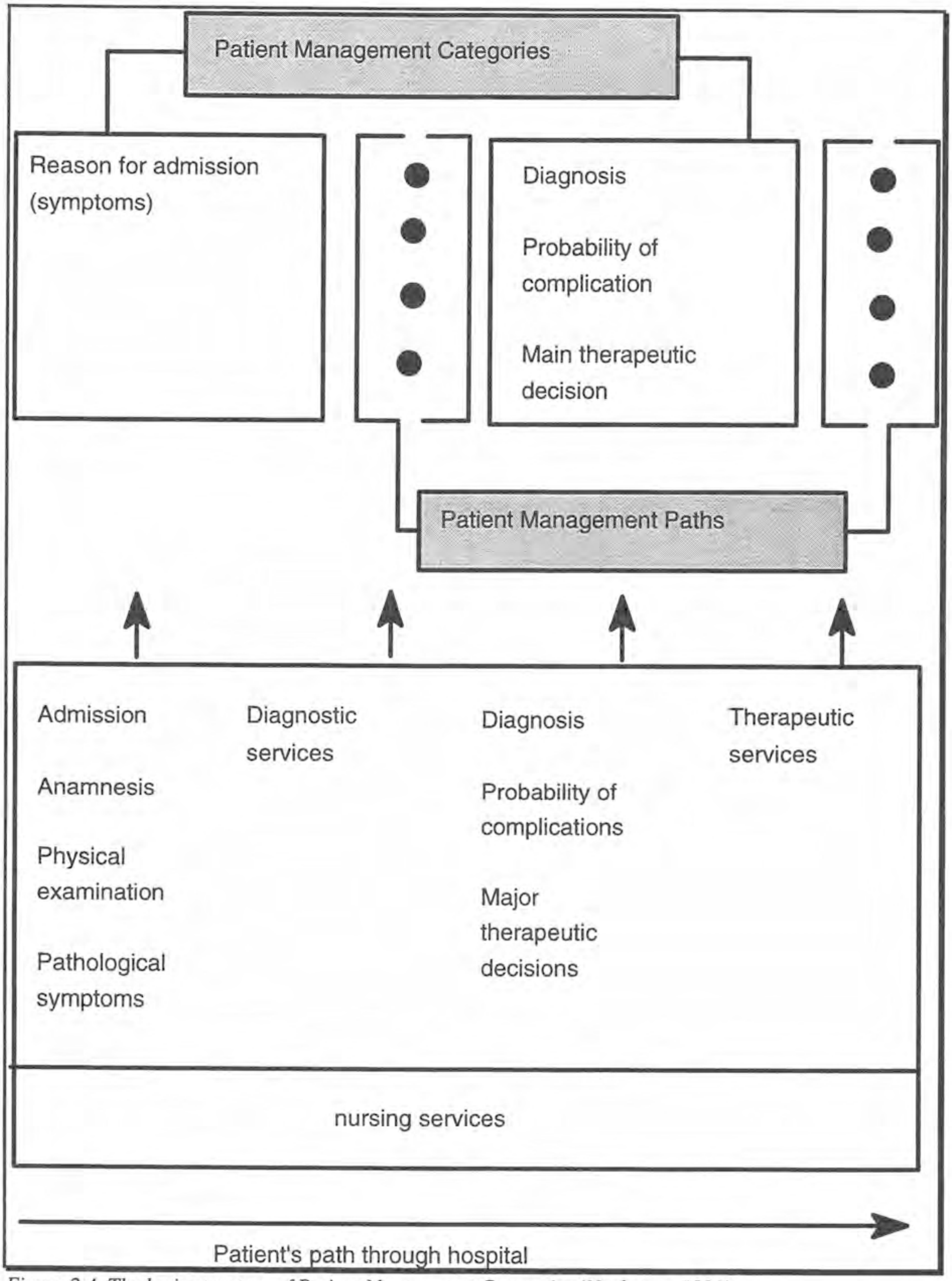

Figure 2.4. The logic structure of Patient Management Categories (Neubauer, 1993)

As a matter of fact, neither system clearly specifies the amount of different resources used in the delivery of services, and neither system explicitly takes into account the nursing resources used (Levine et al., 1984; Buckle et al., 1991). None of the above mentioned patient classification systems are useful in predicting nursing resources.[15]

Another conceptual weakness of DRGs seems to be its lack of resource homogeneity (Rosko, 1988). Resource heterogeneity means that there is variation in the length-of-stay within one DRG category as well as that the length-of-stay does not necessarily reflect the real consumption of other resources [16]. Rosko (1988) reports that in many cases DRGs could not explain more than 50 percent of the variance in the length of stay (LOS) or cost per case. In general 'within DRG LOS variability' can be attributed to different causes such as severity of illness, medical practice variation, outliers and bad coding practice (Rosko, 1988). The severity of illness has received the most attention because there seems to be a high correlation between the severity of the patients' illness and the amount of resources consumed (Sharkey et al., 1993). The important question for this study is how the uncertainty due to LOS variability within DRGs has an impact on the estimations of expected resource utilisation. This question will be dealt with in a later section.
The kind of speciality determines how the performance of PMCs in terms of resource homogeneity relates to the performance of DRGs. In a study of the National Health Service in the UK, it was found that for surgical cases, the DRG system achieves a better resource homogeneity performance than PMCs while PMCs performs better in some of the medical specialities (Bates, 1994)[17]. Another study (Calore et al., 1987) did not find any evidence that PMCs explained more of the variance in cost per case than DRGs.

The whole severity discussion has started a whole range of studies trying to modify or refine the DRGs (Roger-France, 1990). Horn (1983) suggested to refine DRGs by incorporating a Severity of Illness Index. Coffey et al. (1986) and Calore et al.(1987) suggested to use disease staging as severity measure within DRGs. Calore et al.(1987) even suggested to use PMCs as a DRG modifier. Thomas et al. (1991) assess the explanatory power of six severity of illness measures within DRG categories and the study of McGuire (1991) compares DRG refinement using the Computerised Severity of Illness Index and the Refined DRGs as developed by the Health Systems Management Group. The results of these research studies are the development of conceptually better DRG systems such as the AP-DRGs and the APR-DRGs (see previous section).

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[15] The CSI/CN (CN = classification for nursing) has been developed using the CSI system in order to predict resource use.

[16] The latter aspect will be discussed in section 2.4.

[17] Iso-resource performance is measured here as the proportion of bed days within a specialty that belongs to groups with a coefficient of variation below a given level.

External validity

The DRG system is described as an innovation which has been diffused over many different countries. In their book, Kimberly and de Pouvourville (1993) describe the adoption of the DRG system in different Western Europe countries such as England, France, Sweden, Switzerland, Portugal, Norway and Denmark. Several other authors have recognised the many DRG projects going on in countries all over the world (Rodriguez, 1989; Roger-France et al., 1989; OECD, 1990, Casas, 1991). Furthermore, and essentially, the DRGs are considered as 'a language for communication across professional boundaries' (Packwood, 1991, p.167) and are generally accepted as a product(-line) definition for hospitals (Spiegel, 1986, p.88 and Burik et al, 1981). The hospital is a multi-product firm as reflected by its case-mix (Fetter, 1986). This international interest in the DRG system and the many studies about the applicability of the American system in Western-European countries support the external validity of the DRG system. Furthermore, the Belgian government has supported studies to validate the use and the homogeneity of DRGs in the Belgian health care system (see e.g. Closon, 1991).

The main problem with PMCs is that there is much less empirical evidence proving the usefulness of the system outside the US health care system. It should be studied if the general structure of the American PMC system can be transferred to European countries. Treatment patterns in the US. and Europe could be different (McPherson, 1990). The NHS (Bates, 1994) study clearly reports considerable differences in practice between England and the US. Examples of such differences are the use of tests, the workup before admission and the many 'extravagant' procedures/tests (Bates, 1994). Germany is the only country where PMCs and not DRGs are extensively studied for financing purposes, but experiments are still in an early stage (Neubauer, 1993). This lack of empirical validation outside the US. diminishes considerably the validity of the PMC system for use outside the US.. Furthermore, the DRG system and the related software are much more known and implemented (Lichtig, 1986), and they have received much more critical review and testing than PMCs.

Acceptability, reliability and practicality

The most important factor determining these criteria is that the Belgian government has clearly chosen for DRGs as the basic patient classification system in the hospitals (Roger France, 1993). There are two important factors which explain the adoption of DRGs in Belgium within the framework of a revision of the system for financing health care (Roger France, 1993, p.64-73). The generalised use of DRGs in the majority of US. states makes the acceptability of this system much higher relative to the other patient classification systems. This has been supported by the fact that the DRG grouper software was more easily accessible at an affordable price than other systems such as PMCs. Furthermore the data necessary for assigning DRGs to patients are readily available through the mandatory registration of minimum clinical abstract data (since

1990) and the mandatory coding of diagnoses in terms of ICD-9-CM (since 1979). The absence of knowledge in Belgium about any of the other patient classification systems prohibits their use as the basic component in a planning system which must be implemented in hospitals in the future.

The main practicality consideration is the availability of DRG grouper software in the Belgian hospitals. We believe that an increasing number of hospitals will buy such grouper software taking into consideration the intention of the Belgian government to use case-mix data (defined in terms of DRGs) to compare hospital operational performance, and to base a part of the hospital budget on the hospital case-mix as well as to review patient care practices of professionals using case-mix data (Decoster, 1994). In doing so, the Belgian government will adopt the AP-DRGs as the standard system. The AP-DRGs are from a clinical point of view much more acceptable than the basic HCFA DRGs without leading to a multiplication of patient categories as in the APR-DRGs.

Finally, the current knowledge and use of DRGs in the Belgian hospitals increase the experience of practitioners with this system so that the occurrence of the different kind of errors (which has an impact on reliability) has decreased during the last couple of years.

Conclusion

Table 2.3. evaluate each of the patient classification systems on the five different criteria.

Table 2.3. Patient classification systems and their performance (Each patient classification system is classified from 1 (best) to 4 (worst))

	Internal validity	External validity	Reliability	Acceptability	Practicality
DRGs	2	1	1	1	1
PMCs	1	2	2	2	2
Disease Staging	4	n.a.	n.a.	n.a.	n.a.
SII/ CSI	3	n.a.	n.a.	n.a.	n.a.

n.a. = not applicable because not further involved in the discussion

Although the classification system of PMCs have some characteristics which better fit with the task of service requirements planning (such as the patient management paths), the performance of PMCs in predicting variation in resource consumption has not been evaluated as remarkably better than the performance of the DRG system. We believe that the more 'implementation' oriented arguments still exceed the inherent conceptual weakness of DRGs (in light of service requirements planning).

The previous discussion introduces some questions as to the choice of the DRG system as a system for internal management in hospitals. We need some more empirical evidence about the performance of other patient classification systems before we dare to recommend one of these systems above DRGs.
The above discussion about the performance of the DRG system in the context of this study also learns that care must be taken in assessing the level of resource-homogeneity within a DRG group when using DRGs to describe the patient flows in a hospital service requirements planning system. Perhaps the DRG must be extended with a CSI in order to better capture the severity of illness which seems to be a very important determinant of resource use.

2.2. The capacity structure of hospitals

In a previous part, we have indicated that there exist dependency relationships between the different capacity resources in the hospital. Describing the capacity structure of a hospital means that the different resources and their interrelationships are studied (Vissers, 1994, p.24). In this part, we are going to describe the capacity structure of the specific unit of analysis of this study.

We have limited the scope of the study to these patients flowing through the heart surgery department of the University hospital in Gent. In fact, these patients are a selective group of coronary care patients where the selection criterion is based on the presence of a surgical procedure. We have collected and analysed data on 364 cardiac surgery patients which were admitted in this Belgian hospital in 1992. The database contains patients with one or both of the following principal diagnoses: coronary artery bypass grafting (CABG) and cardiac valve replacement procedure (CVRP) [18]. Some patients with CABG or CVRP as principal diagnosis are not included in the final database because:

1. the patients resides in a department which does not belong to one of the departments which are subject of this study (see further). One example is a group of children with this kind of surgical procedure but residing on the paediatric department in the postoperative stage.

2. the registration in one of the databases was wrong and could not be corrected (see remark in the following section on data validity).

Table 2.4. on the next page shows some general characteristics of the patients. It is important to note that the admission of most of the patients are scheduled. In many cases, the date of admission is scheduled after a diagnostic procedure during which catheterisation or

[18] Data are collected for 8 months in the case of CABG patients and for 12 months in the case of the CVRP patients because there are relative more CABG patients than CVRP patients.

coronarography is performed. This diagnostic procedure is often performed some weeks before surgery (and patients are sent home in between). This further means that we assume that the diagnosis is approximately known. The operational characteristics of the diagnostic process are quite different from those of the therapeutic process (HBS, 1985).

Table 2.4. General characteristics of the sample of 364 patients

	Total	DRG104	DRG105	DRG106	DRG107
Number of patients:	364	38	87	112	127
Sex:					
Male:	70%	50%	67%	67%	80%
Female:	30%	50%	33%	33%	20%
Age:					
< 50 years	8%	3%	11%	7%	8%
50 yrs <= x < 60 yrs	24%	21%	25%	18%	30%
60 yrs <= x < 70 yrs	44%	29%	44%	46%	46%
> 70 yrs	24%	47%	20%	29%	16%
Nature of admission					
Emergency	7%	16%	1%	12%	3%
Scheduled	84%	74%	93%	71%	92%
Unknown	9%	10%	6%	17%	5%
Nature of referral					
Specialist of the hospital	21%	45%	21%	21%	13%
Specialist not of the hosp.	67%	32%	76%	58%	80%
Other hospital	4%	8%	1%	8%	2%
Other (GP,...)	0.5%	2%	1%	0%	0%
Unknown	7.5%	13%	2%	13%	5%
Destination after discharge					
Home	85%	71%	85%	84%	91%
To other hospital	9%	13%	12%	10%	6%
To home for the elderly	1%	3%	1%	2%	0%
Death	4%	11%	1%	4%	3%
Other	1%	2%	1%	0%	0%
Catheterisation procedure during the last three months (in a separate admission) ?					
Yes	45%	0%	77%	0%	75%
No	40%	84%	13%	75%	15%
Unknown	15%	16%	10%	25%	10%

Data on the 364 patients are collected in order to learn more about the characteristics of the service delivery process of those cardiac surgery patients. These characteristics will be helpful in defining the service requirements in the HSRP system as well as in the modelling of the flow of these kind of patients through the different service units of the hospital.[19]

Using DRG grouper software (HCFA DRGs, 6th Revision) the 364 patients are classified in 4 DRG groups: DRG 104, 105, 106 and 107 (see column 3-6 in table 2.1). Figure 2.2 in a previous section shows the basic decision tree used for classification. It can be observed that the kind of procedure performed and the presence or absence of a cardiac catheterisation procedure during the stay is an important factor in the grouping.

These 364 patients remain on one or more of the following departments of the hospital: cardiology, heart surgery (medical care), heart surgery (intensive care) and the general intensive care.[20]

The limitation of the scope of the study to this kind of patient flows and these kinds of departments is based on the following arguments:

1. Simulating the behaviour of a total hospital system is very difficult (Valinsky, 1975; Jeang, 1990). The system is complex. This is even more true for the University hospital. There are two possible ways to limit the scope of the model: (1) put the focus on the planning of one resource as for example in the so-called bed planning studies (e.g. Dumas, 1984 and 1985; Harris, 1985); (2) study the planning of one department or unit where multiple resources can be considered. The study of progressive patient care facilities such as maternity and coronary care are examples of the latter way of restricting the focus.
Furthermore, building and validating a simulation model with a fairly complex structure are very time-consuming activities. Ultimately the purpose of this study is not to build a simulation model but to use a simulation model in an experimental design.

2. The treatment of the kind of coronary care patients considered in this study occurs relatively independent from the treatment of other patient groups. For instance, there is a specific dedicated medical and intensive care unit for heart surgery patients. This makes the analysis of the capacity structure easier. Furthermore the treatment pattern of this kind of coronary care patients is quite predictable (and standardised) compared with many other patient groups. Observation in several US. hospitals learns that these patient groups are often one of the first groups for which clinical pathways are developed.

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[19] In a later section, the reader will observe that data on these 364 patients were very helpful in defining the structure of the bill of resources, which is key tool in HSRP. Furthermore, based on the data,we have defined the transition probability matrix in the simulation model which has been developed for this specific study.

[20]. Other patients with the same surgical procedure, but staying on other hospital departments (such as pediatric care) are excluded from the study.

Furthermore, it is much easier to identify stages in the treatment of surgical patients (preoperative, surgical and postoperative) than of medical patients.

3. The minimal clinical data that have been collected for this kind of patients in the University hospital are evaluated as fairly valid .[21]

Before discussing the capacity structure of the heart surgery unit, it is important to introduce the concept of workstation and the concepts of 'leading' and 'following' resources. A workstation is a point in the care delivery process which requires a mix of resources to contribute to production (Vissers, 1994, p.24). For instance the operating room is such a workstation requiring the involvement of surgeons, anaesthetists, nursing staff, equipment and materials. Workstations have the capacity to generate services. In this study, we have identified four workstations: cardiology, heart surgery (medical care), heart surgery (intensive care) and the general intensive care. Each of these workstations uses a combination of personnel, accommodation, equipment and specialist-time to treat patients. An important remark is that in this study the surgical room is not considered as a separate workstation, but it is part of the intensive care workstation of the heart surgery department.
The intensive care work station has been identified as a bottleneck workstation. The mean occupancy rate of the 6 intensive care beds was 92% (in 1992). Taking into account that the occupancy of this unit during the weekend can be lower, occupancy of more than 100% is sometimes reached during the week. This means that one surplus bed is added to the unit. The consequence of the high occupancy of the intensive care unit is that some patients need to stay longer in the surgical room. This phenomenon is called 'blocking' (Cohen et al., 1980). In the other cases, patients in the intensive care unit are discharged earlier and transferred to other units (such as the midcare). This is called 'bumping' (Cohen et al., 1980). Blocking and bumping clearly show the dependency of the capacity requirements of the different workstations.

A resource is leading *"if it is the trigger for generating production on other resources, which 'follow"* (Vissers, 1994, p.16). In our case, the leading resource is the surgery room capacity. The date on which surgery is scheduled determines the timing of the capacity requirements such as medical care beds and nursing and also determines the admission date. Vissers (1994) further remarks that the production of the surgical room is completely dependent on the availability of specialist-time which must be shared with other departments such as the outpatient department (Vissers, 1994, p.28).

The importance of the surgical date in our case study can be shown with the protocol which is used on the heart surgery department (figure 2.5). The protocol clearly shows the central

[21]This is based on conversations with the medical informatics department which is responsible for collecting the minimal clinical data of all patients in the hospital.

position of surgery in the planning process. It further learns that laboratory, radiology, cardiology (clinic) and physiotherapy are the most important ancillary services supporting the primary care process of these heart surgery patients. Laboratory and radiology are diagnostic workstations while physiotherapy is a treatment workstation (Vissers, 1994). These workstations are shared by patient flows with other diagnoses as well as by the outpatient flow.

Preoperative stage

Meeting with the heart surgeon, the cardiologist, the anaesthesiologist, the physiotherapist and the nurses.

Day (-2)
- Admission

Day (-1)
- Blood tests (Laboratory)
- Chest X-ray (Radiology)
- Echocardiogram (Cardiology clinic)
- Blood (blood ....)

Surgical stage

Day (0)
- 7.45 am 1st patient to the OR
- 12.00 am 2nd patient to the OR
- Patient goes to the Intensive Care unit (ICU)

Postoperative stage

Meeting with the heart surgeon, the cardiologist, the anaesthesiologist, the physiotherapist, nurses and the social nurse of heart revalidation.

Day (+1)
- Patient is sometimes transferred from the ICU to the midcare unit

Day (+2)
- Blood tests (Laboratory)
- Patient is transferred from the ICU to the medical care unit

Day (+5)
- Blood test (Laboratory)
- Chest X-ray (Radiology)
- EKG (Heart surgery)

Day (+7)
- Blood tests (Laboratory)
- Echocardiogram (Cardiology clinic)

Day (+8)
- Blood tests (Laboratory)
- Chest X-ray (Radiology)
- EKG (Heart surgery)
- Physiotherapy (Revalidation)

Day (+9)
- Discharge

Figure 2.5. The protocol used on the heart surgery department

The clinic of the cardiology department also deliver some ancillary services to the heart surgery department. The most important one is catheterisation. Catheterisation is not mentioned in the treatment protocol because it is a diagnostic cardiovascular procedure which is performed

before a treatment plan can be made up. Patients requiring a catheterisation are admitted on the cardiology department. For approximately 50% of the patients, this procedure has been performed before the current admission. Some patients may not go home after the catheterisation procedure because of the severity of their disease. They are often transferred from the cardiology unit to the general intensive care unit until the surgery is going to be performed.
There is an important relationship between catheterisation and the surgery rooms. There must be a surgery room available when some of the catheterisation procedures are executed.

The performance of these ancillary services can have an important impact on the throughput time of the patients. One reported example is that a too high turnaround time of test results (radiology and laboratory) increases the length of stay of patients in the catheterisation department. The same problems have been reported by the intensive care workstation, but in this case they do not have to wait on the results because they have their own (limited) test equipment. Figure 2.6. shows the capacity structure of the heart surgery unit.

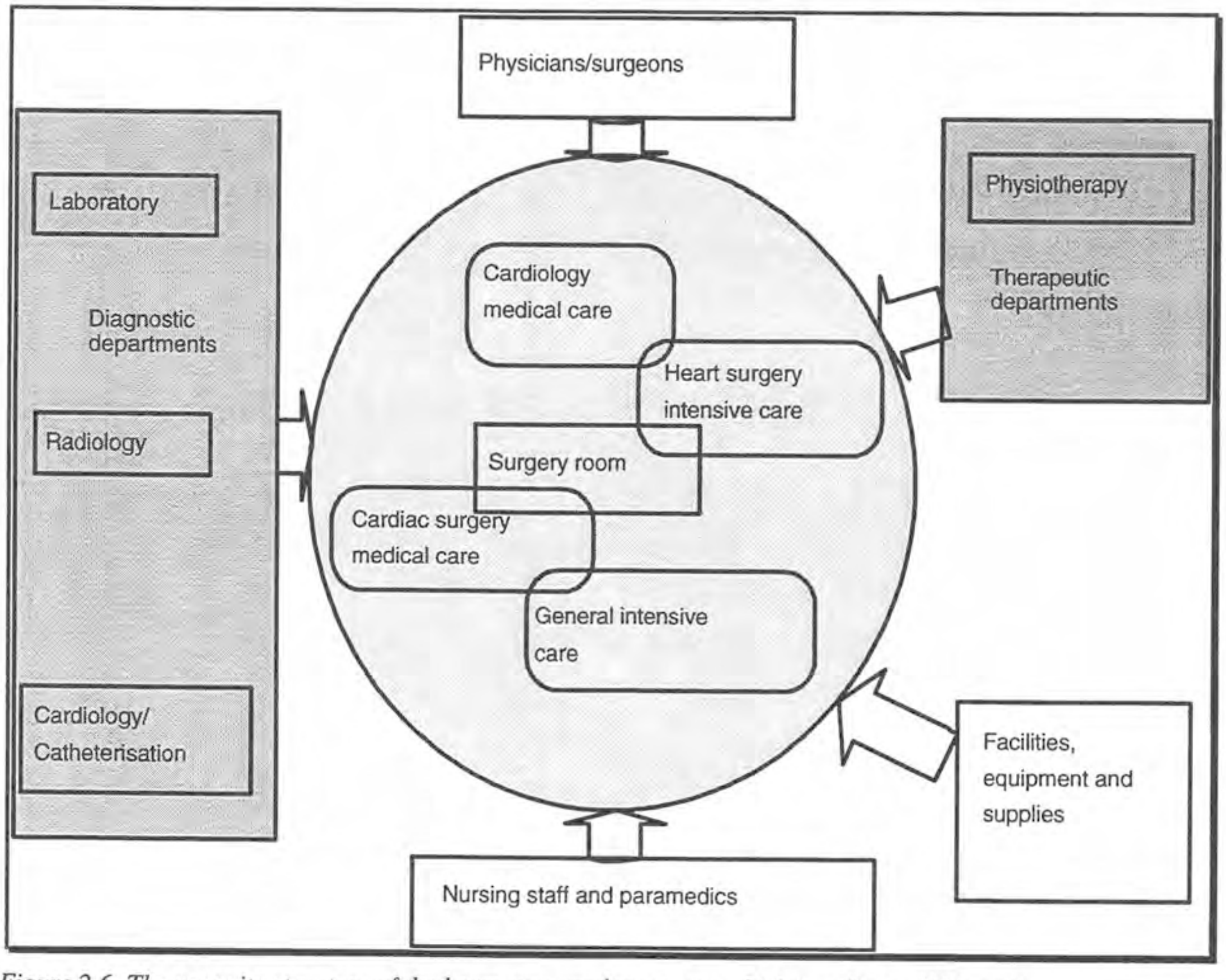

Figure 2.6. The capacity structure of the heart surgery department which is subject of this study

2.3. Case-based resource management data

In the previous section, we have already indicated that data and databases are very important in the construction of the tools for service requirements planning in hospitals. In this section, we describe the data requirements and how these data requirements can be collected in a Belgian hospital.

Service requirements planning in hospitals can be considered as an application of case-based resource management. In case-based resource management, the individual patient is the basic unit for data collection (Bullas, 1989). The most important characteristic of a case-based resource management database is the merging of clinical and financial data with the patient as common denominator (McMahon, 1994). The merging of clinical and financial data is a necessity when resource use data for product-lines must be collected. In other words, the availability of case-based resource management data is a condition sine qua non to apply service requirements planning in hospitals. We want to remark that the development of case-mix cost accounting schemes also requires the merging of clinical and financial data (Ahrens et al., 1980; Nederstigt, 1985, pp. 186). As to the information requirements, hospital service requirements planning and case-based cost accounting have a lot in common. They both need the development of a treatment profile (Verheyen et al., 1992).

In the preliminary study in the American hospitals (see appendices 1 and 2), we found that the merging of clinical data and financial data is often in a starting stage. There seems to exist a 'historically' grown distinction between administrative and clinical information systems. In collecting data on the cardiac surgery patients, we have personally experienced the problems with non-integrated information systems. In the case of the Belgian University Hospital, we have spent several months in acquiring the databases and adapting them in such a format that they can be linked using a personal computer. One example of the problems encountered is that although the patients are uniquely identified in each of the databases, the identification key has not the same format in the different databases. Another problem we had to deal with is the confidentiality of the data. We received the permission of the medical staff and of the ethical committee to use the data after the promise that the data will only be used in aggregate form, i.e. individual patients may not be recognised.

A fundamental option in this study is to build the case-based resource management database using data from information systems already in operation in the hospital. During the preliminary case-studies in American hospitals, we observed that nurses already spend a large amount of their time on documentation and data collection. One of our points of departure is that the implementation of a service requirements planning system in hospitals may not lead to additional (or special purpose) data collection. In this section we describe the (existing) key databases used. In order to learn about these existing databases, we studied the data collection process in the University Hospital. This in-depth study is based on interviews, a study of the structure of several databases and bringing together and linking the databases for the group of 364 heart surgery patients (see appendix 6).

One very important methodological remark is that we use the observed resource utilisation pattern, which must be distinguished from required resource utilisation. Observed data may reflect the use of unnecessary services, outcomes that reduce efficiency, diminish effectiveness and may fail to improve the quality of the product. This implies that this kind of data must be added with a discussion about the existing process. (This can be done within a context of continuous improvement).

The two main components of a case-base resource management database are (Lichtig, 1986, p.169): (1) a patient classification system and (2) measures of resource use. Both allow to condense the overwhelming amount of data into management information (McMahon et al., 1994). In a previous section, we discussed patient classification systems; in this section, we further discuss measures of resource use (MRU).

2.3.1. Measures of resource use (MRUs)

To be useful as a management support tool for either administrators or clinicians, the data must be summarised into sensible units (McMahon et al., 1994). For resource management applications, we are looking for measures of resource use. A measure of resource use is "a unit of service that indicates the quantity of a hospital service consumed by the patient" (Lichtig, 1986). The best known basic measures of patient's resource consumption are charges and length-of-stay (LOS) (Berki et al., 1984).

For ancillary services, the billed charge is most often used as MRU (Lichtig, 1986, p.170). The advantage of this kind of MRUs is that they are readily available and relatively easy to use, but the disadvantage is that the underlying assumption of charges uniformly related to costs within a department is quite dubious.

As to the question whether LOS is a good indicator of resource consumption, Wickings (1987) remarks that no single figure is able to catch the pattern of resource consumption of any one patient. Research over the past 20 years has identified that there are many determinants of variation in resource consumption (see for instance Webb et al, 1976; Lave et al., 1976; Berki et al, 1984; McMahon et al, 1986; Rhodes et al., 1986; Patterson, 1987; Sharkey et al., 1993). The following table summarises these determinants.

Table 2 .5. Determinants of variation in resource consumption in addition to length of stay.

CATEGORY	SPECIFIC DETERMINANTS
patient non clinical characteristics	age, sex, distance from domicile to hospital, method of payment
patient clinical characteristics	number of diagnoses, timing of radiological services, timing of laboratory services and intensity of nursing services, accommodation days or number of days spent in a certain unit
hospital efficiency specific characteristics	laboratory turnaround time, the time lag between the event of admission and the initiation of the service flows, admission, discharge and procedure scheduling, occupancy rate
physician practice dimensions	board certification, age and years of experience and other
stay-related factors	day of the week of admission, type of admission, preoperative stay, discharge status

The complex nature of the pattern of resource use in hospitals encourage more research on other measures of resources use. One of the underlying assumptions of length of stay (LOS) as a measure of resource use is that resources are utilised for the same amount each day during the stay of a patient. While this assumption may be feasible for the more 'hotel' related (accommodation and some ancillary) services, it is not acceptable for case-management related services (Berki et al., 1984). One way to deal with this problem is 'dissecting' the hospital stay (Sherman et al., 1980). The separate use of days for each accommodation department (intensive care, paediatrics.) results in a 'dissected' LOS measure, the so-called accommodation days (Lichtig, 1986). Again there is the assumption that each patient in a unit receives essentially the same amount of resources per day (Lichtig, 1986) . This may not be true for more case-management related services such as radiology and laboratory services (Berki et al., 1984). This means that we need to add case-management related measures of resource use such as timing of services and service intensity. Service intensity measures the quantity of resources required to treat a given type of case per day of stay (Luke, 1979). The timing of services "measures the relationship between the temporal flow of services and days of stay" (Berki et al., 1984). An example is the proportion of time spent on the intensive care unit relative the total length-of-stay. Berki et al. (1984) make a very interesting analysis of these two measures. In case of the 'hotel' related services, these measures reflect the efficiency with which these services are delivered. For the case-management-related services, variations in these measures are "more likely to reflect variations in patients' clinical characteristics". The underlying assumption is that these two measures are an indication of the severity of illness which itself is considered as the most important determinant for resource use (Sharkey et al., 1993).

One problem with the service intensity and the timing of services measures is that there are as many measures as different services. Furthermore they give no indication of the amount of resources which are required to produce a particular service (e.g. chest X-ray) in a particular department (e.g. radiology). In order to do so relative value units (RVU) are developed (in the US.), measuring the resources required to perform a service compared to some standard service (Lichtig, 1986; McMahon et al., 1994). For instance a RVU scale has been developed by the American College of Radiologists. A standard chest X-ray has a value of 1 RVU, while a cardiac catheterisation has a value of 60 RVUs. In order to assign RVUs to a particular service, such factors as staff time, staff skill level and sophistication of equipment are taken into consideration (Lichtig, 1986).

2.3.2. The construction of a database for case-based resource management within Belgian hospitals

Our resource management information systems includes two databases (figure 2.7.): a patient database and an event-history database. The patient database mainly include data on patient characteristics and stay-related factors. These data were automatically obtained from one key database which is operational in Belgian hospitals, the so-called Minimal Clinical Data. All Belgian (non-psychiatric) hospitals must register Minimal Clinical Data since 1990 (KB, June 21, 1990). It is a summary of pathology and therapeutic data on hospitalised patients. Table 2.6. shows how patient characteristics and stay-related factors can be obtained using these Minimal Clinical data.

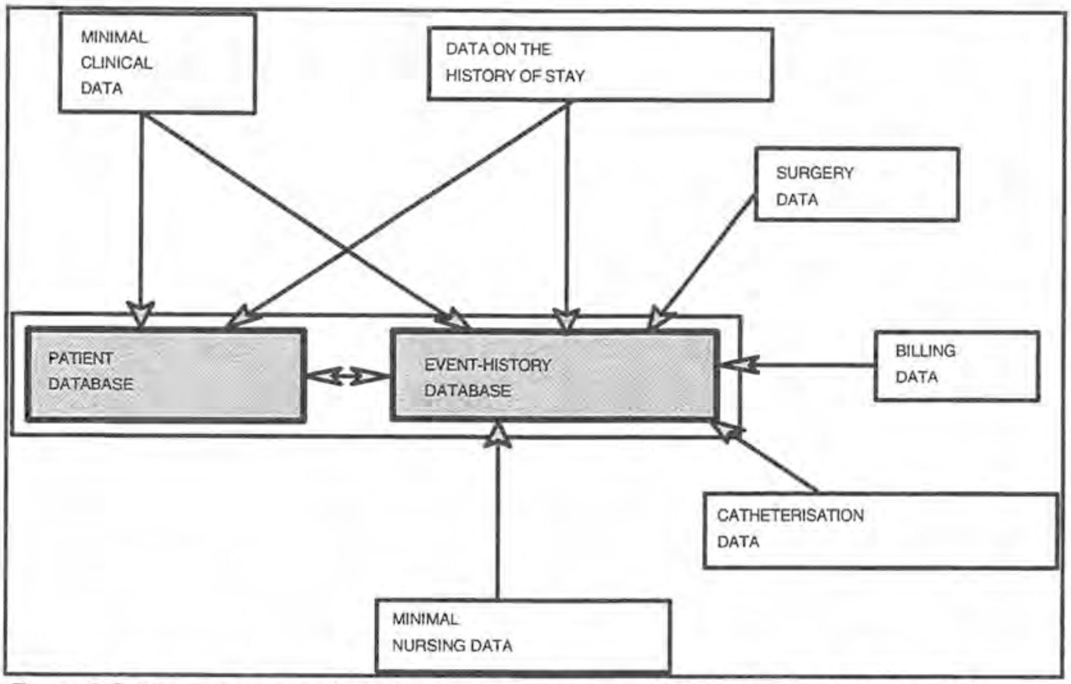

Figure 2.7. Designing a case-based resource management database using data already in operation in the hospital

Table 2.6. Patient characteristics and stay-related factors extracted from the minimal clinical data

CATEGORY	DETERMINANTS OF RESOURCE USE	MINIMAL CLINICAL DATA-ITEMS
Patient non clinical characteristics	Age	Birth Date
	Sex	Sex
	Distance from domicile to home	Postal code
Patient clinical characteristics	Number of diagnoses	The principal diagnosis and secondary diagnoses using ICD-9-CM codes
		A procedure code and degree of urgency
	Accommodation days	Length of stay on intensive care (< 12 hrs, 12 hrs - 24 hrs, 1 day,..)
Stay-related factors	Day of the week admission	Calculation based on the admission date
	Type of admission	Type of admission (emergency, scheduled, internal transfer,...)
	Discharge status	Discharge status (dead, on medical advice, without medical advice,...)
	Destination	Destination of the patient (home, other acute care hospital, psychiatric hospital, dead,...)
	Preoperative stay	the difference between date of surgery and admission date

It must be remarked that the Belgian government wants the Minimal Clinical Data to be used for internal hospital management purposes. Patient clinical characteristics and hospital efficiency specific characteristics which are able to better explain variations in resource use are not covered by this patient database. In fact there is no information on timing and intensity of specific service use because medical activities are not registered in the Minimal Clinical Data. That's why we have constructed the event-history database.

The event-history database shows the history of the patient stay in the hospital. In our particular study, it indicates the sequence of the clinical departments where the patient has remained during the period of hospitalisation. For instance a patient who has moved from 'medical care heart surgery' to 'intensive care heart surgery' and back to 'medical care heart surgery' is presented in this event-history database through three records indicating the three stages.

A fundamental difference between the patient database and the event-history database is the level on which a record is defined. In the former it is on the level of the patient, in the latter on the level of a stay of the patient in a certain stage. In the record of one stage, data on the events which have occurred during this stage can be recorded. This event-history database allows to register a resource consumption pattern. In order to obtain this pattern, it must be known which services are delivered to the patient during which stage. Several other databases operational in the hospital give information about providing a particular kind of service (e.g. surgery, chest X-ray, electrocardiograms, catheterisation, nursing,..) on a particular date.

A surgery database kept by the anaesthetists indicates the kind of surgery, the date on which it is performed and the time it took to perform it. Because surgery is always performed during the intensive care stage, this data can be easily assigned to the records of the event-history database. In the same way, data is extracted from a database recording the date and kind of catheterisation. In this last database, no data is available on the time it takes to perform a catheterisation.
Data on the delivery and the timing of ancillary services such as radiology and laboratory can be obtained from the billing document. For our purpose, the three most important data-items of the billing document are: the nomenclature number which allows to identify a particular service, the date on which the service is delivered and the department where the patient belongs when the service is delivered. An important decision is the level of detail on which services are identified. For instance, the nomenclature [22] makes a difference between a chest X-ray with one plate or a chest X-ray with 2 or more plates. When considering this as one kind of services, there must be some way of weighting the services relative to each other. In this case, the basic charges for the services can be used. We do not recommend to use charge data as a general measure of

[22]. In the nomenclature, all forms of medical activities are coded by the National Institute for Reimbursement of Health Care (RIZIV).

resource use because this kind of data is not really a reflection of the cost input (Lichtig, 1986; McMahon et al., 1994). But for the same kind of services (within one ancillary department) the bias can be 'equal' so that the charge of one service relative to another can give some acceptable indication of resource use. In any way, it is indispensable to study in more detail how a particular charge is developed before using charges as measure of resource use.

The current interest of the Belgian hospitals and the Belgian government in developing cost profiles for patient case types will promote the development and the use of MRUs which are more accurate than charges and length of stay. For example, standardised times for surgical procedures need to be developed through a panel of experts in order to estimate the financial requirements of operating theatres (Decoster, 1994, p.149). Activity based costing can also be very useful in developing cost profiles (Ramsey IV, 1994).

In this study, we decided to use the billing data to count the number of services (e.g. Chest X-rays) which have been delivered to patients. The charge is not used as a measure of resource use. The complication of this decision is that our HSRP is only able to tell the radiology department how many chest X-rays are required in the next period without giving indication of the workload related with these service requirements. Taking into account the fact that HSRP does not want to schedule the activities within ancillary departments, we think that this approach is acceptable.

Last but not least, data on nursing services must be available. Although the nursing department of the hospital has a developed nursing staffing and scheduling system, this system is not case-based. In other words, it is not possible to assign the nursing workload to the individual cases or patients. This kind of assignment requires a special purpose study using work sampling with the assignment of patients to the categories of nursing patient classification systems (Warner, 1976). Such a special purpose study is against our fundamental point of departure that only databases are used which are already operational in the hospital. In Belgian hospitals, data on nursing activities are also collected in the Minimal Nursing Data (MVGs) . The Minimal Nursing Data are a care registration system based on nursing activities in order to reflect the specific identity of the nursing unit. The focus is on 23 nursing activities which are registered during four fifteen-days sampling periods scattered over a year (Ministerie van Volksgezondheid en Leefmilieu, 1992). MVGs are not designed for measuring nursing workload but several studies are going on to see whether these minimal nursing data can be linked with a nursing patient classification system (Sermeus, 1993; Van Damme, 1990; Goedertier, 1992). These studies are too preliminary to be of use in this study. Furthermore, several authors are not convinced that the DRG system is homogeneous as to the nursing care requirements (Thompson et al., 1991). In fact, the DRG system covers a medical model and such a model does not explain nursing practice. Closon (1991, p.349) shows that the DRGs only explain a very small percentage of the variance of nursing care per stay. The study of Closon (1991) also reveals that the explicative power of DRGs is much greater when the daily nursing care intensity is measured instead of the nursing care needs over the whole stay. More in depth study of the relationship between DRGs and nursing care is needed before using DRG based nursing measures of resource use. The result of these problems is that we do not have any information on the case-based workload but we believe that in the future such information will be routinely available.

Finally, it is possible to bring a summary of the event-history into the patient database. Therefore the specific sequence of stages (departments) for a patient must be summarised. One way of doing this is by defining this sequence as a path, characterised by a number. A different sequence implies a different path number. In this way, patients which have the same flow through different service units of the hospital can immediately be recognised (Fetter, 1969). The routing or the flow is an important element for scheduling purposes.

Figure 2.8. and 2.9. show the resulting field structure for one record in both databases. These databases are mainly used in the development of the bill of resources for the different DRGs in this study. Of course, one must spend some time to assure the validity of the data. We observed several errors in the different databases (e.g. patients who are not included in the event-history database, but are included in the patient database) or patients with different admission dates in the both databases. We have corrected as much errors as possible. Some patients are omitted from the analysis because of incomplete records (see a previous remark).

Patient ID number	Age yrs	Sex	Post-code	Admission date	Admission hour	Discharge date	Discharge hour
XXXXXX	76	m	9000	27/04/98	16.00	10/05/98	11.00

LOS in days	LOS in hours	LOS in ICU	No of diagnoses	Type of admission	Discharge status	Destination	Path ID
13	308	2 (*)	5	5 (*)	1 (*)	1 (*)	1

(*) = codes which are used in the Minimal Clinical
Data: LOS on ICU = 2, i.e. 2 days on ICU
Type of admission = 5, i.e. scheduled
Discharge status = 1, i.e. on medical advice
Destination = 1, i.e. to home

Figure 2.8. The record structure of the patient database

Patient ID	Clinical Dpt	Admission date	discharge date	No of surg. procedures	OR time	Chest X-ray	ECG	......	LOS in hrs
XXXXXX	8140C	27/04/98	30/04/98	-	-	1	1		68
XXXXXX	8327C	30/04/98	01/05/98	1	3.5	1	-		54
XXXXXX	8140C	01/05/98	10/05/98	-	-	3	1		214
YYYYYY	....								

Figure 2.9. The record structure of the event-history database

2.4. Transferring concepts from the manufacturing planning and control theory

The research on hospital service requirements planning started with the perception of some researchers that there are some clear analogies between a DRG (as product or end-item of a hospital) and an end-item of manufacturing firms as defined in materials requirements planning (MRP). MRP as part of Manufacturing Resources Planning (MRP II) is one of the most familiar information systems for manufacturing planning and control in manufacturing firms (Vollmann et al., 1992). MRP supports the production planning and control task by linking information over the future customer demand with an integrated model of the production process. "Generally, MRP outputs enable managers to determine the timing and quantities of material purchases and component production required to satisfy customer finished goods demand in a timely and cost-efficient manner" (Cooper et al., 1990).

The use of a MRP system to plan materials (storable resources) in a hospital context has been suggested and documented by several authors (e.g. Showalter, 1987 and Tomas, 1990). Articles written by Showalter et al. (1984) concerning hospital food services and by Steinberg et al.(1982) on surgical services provide evidence that MRP is a viable approach to inventory management in a hospital.

Nonetheless we have already indicated that investments in inventories are in most hospitals only a fraction of the investments in technology and people. According to Siferd et al.(1992b), capital-intensive medical technology and the provision of highly skilled nursing services are two of the most important reasons for hospitals to continue to exist in today's cost-conscious health care environment. This means that the hospital is a capacity-driven system and is not material-driven. This is a very important remark when considering the implementation of MRP-type systems where capacity availability is only handled in a secondary way (Roth et al., 1992).

Furthermore the hospital industry belongs to the service sector. A whole literature has emerged over the last decades on the differences between service operations and manufacturing operations (see for example McLaughlin, 1992).

The use of manufacturing concepts -which are developed to manage the material flow- for capacity management in the hospital environments must be considered as a 'transfer of technology' (see Reisman, 1988). Several authors believe in the feasibility of this technology transfer strategy because there are several similarities which have been recognised. Other authors have reasonable doubts to use this kind of technology in a hospital environment because of the differences between the operating environment of the hospital and manufacturing. In the following paragraphs we describe the similarities and differences.

Similarities

Rhyne et al. (1988) and Roth et al. (1991) state that MRP can be used for managing capacity resources in a hospital. These different authors see opportunities in the transfer of this manufacturing management technology to the health care environment because the DRG system allows to identify the products of a hospital in terms of a bundle of services and goods to be delivered to the patients (Freeman, 1991). The lack of a clear product definition for hospitals was in the past the main barrier to transfer manufacturing management concepts because in manufacturing a product is more often clearly defined (Steinberg, 1982; Roth et al., 1991; see also Levitt, 1972).

The pretended usefulness for hospitals of the production planning technique (commonly used by manufacturing firms) was further based on the authors' perception that there are some clear analogies between a DRG (as product or end-item of a hospital) and an end-item of manufacturing firms (as defined in MRP). In manufacturing industry each different product that a company manufactures, can be defined by a **bill of material** (BOM) listing each component that goes into the finished product (Vollmann et al., 1992). In a hospital, each different DRG can be defined in terms of the procedures, services and materials that apply to it (Rhyne et al., 1988; Freeman, 1991). This analogy has been first proposed by Fetter et al.(1985). The current evolution of DRG-based clinical pathways further support the proposition that for each DRG a BOM-like listing of time-phased services and goods can be added (Dowling, 1991).
A second analogy is that of **dependent demand**, one of the most distinctive characteristics of MRP. In manufacturing terms, dependent demand means that the demand for raw materials (component) is derived from or directly related to the demand for higher level assemblies or end products (parent) (APICS, 1979; Showalter, 1987). In hospitals, we recognise two kinds of dependencies: (1) the dependency between a particular patient (DRG) and his/her service

requirements and (2) the dependency of the capacity requirements of following resources on the capacity requirements of leading resources.

There are some other reasons to believe in the usefulness of MRP for planning the resource requirements in a hospital. In a more dynamic, variable context -like job shops - MRP becomes invaluable for planning and release (Karmarkar, 1989). When a hospital is viewed as network of service units with finite capacity through which patients flow, it behaves like a job shop. In this case, the MRP system must be 'action' oriented (Ritzman, 1980). This means that action notices are given when for instance it is time to transfer a patient from one unit to another or when the discharge date of the patient must be rescheduled because of complications.
Furthermore in a process where complex products are produced in low-volume, MRP seems to be invaluable as an information management tool for co-ordination between departments (Karmarkar, 1989). The volume and the complexity of the hospital products depend on how the hospital product is defined (or on how patients are classified) and how many different stages are recognised in the therapeutic process (see further). It has been remarked that the distinctive advantage of MRP over other systems is increasing with a more complex product (Ritzman, 1980).

The due date plays an important role in the co-ordinating task of MRP. In hospitals, the due date is the discharge date or the date on which the whole bundle of services and goods must be delivered. It is nothing else than the admission date increased with an expected (DRG-based) length-of stay. With such a date in mind, the different departments can 'calculate' when their services or goods are 'due' using the dependent demand relationship. This is the particular mechanism of materials requirements planning that, when applied to hospital operations, will guarantee a better length-of-stay performance.

Differences

The following arguments inhibiting the use of MRP in a hospital environment have been formulated:

1. Production control in an industrial setting focuses on the flow of materials or goods while in a hospital the flow of patients is a primary concern (Vissers, 1994, p.21). In the industrial setting, the parent and component in a bill of material are both inventory items. The link between end items and resources is handled through routings and resource profiles (Ritzman, 1980). In the hospital setting, the parent is a patient type (DRG) and the component is a service or resource (Ritzman, 1980). Furthermore, materials can be stocked. This means that production and consumption must not necessarily be simultaneously. This is a completely different situation from the high degree of physical

patient contact inherent in the delivery of health care services. "A high contact environment creates more uncertainty in daily operations due to variability in arrival times and customer requirements" (Smith-Daniels et al., 1988).

2. Most industrial production concepts assume the identification of the exact product (Dilts et al., 1992) and knowledge about specifications of the products, which are only to some extent available in health care delivery (Vissers, 1994, p.21). A bill of material in industrial settings is often stated with certainty. For certain classes of patients, one does not know initially what resources must be applied (Ritzman, 1980) even when the diagnosis has been specified.

3. The representation of a product with a bill of material does not accurately describe the dependent demand relationship in a health care environment. " The bill of material used in MRP systems is an arborescent network in that no part or activity in the bill has more than one part or predecessor " (Smith-Daniels et al.). In health care delivery, several activities may occur simultaneously or in a concurrent way. Health care products can be better described as a project network (Smith-Daniels et al., 1988).

Uncertainty is the difference between the amount of information required to perform a task and the amount of information already available in the organisation (Galbraith, 1973)[23]. According to this definition, there is a lot of uncertainty in hospitals because of the high contact environment, variability in customer requirements and the problem of product identification. It is true that MRP as it was originally conceptualised (Orlicky, 1975) is not able to deal with this higher uncertainty. Nonetheless, the MRP information system has been enhanced with many new features which allow to deal with some limited amount of uncertainty[24]. In this study we look after the feasibility of some specific features to deal with the different sources of uncertainty which are typically found in a hospital environment.

Although there are some important reasons why MRP does not quite fit a hospital situation, we believe that there are sufficient analogies to pursue this study. The following reasoning of Mckelvey and Aldrich (1983) about borrowing the population perspective in the organisational theory from biology, well fits our situation:

[23] It is important to make a distinction between uncertainty and variability (although both terms are frequently used to describe the same phenomenon). Uncertain and variable factors both change from one period to the next but in the case of variability, this amount of change is known in advance while this is not the case for uncertain factors (Brennan et al., 1993). The differences in the average length of stay of different DRG categories indicate variability while the within DRG length of stay variation indicates uncertainty.

[24] In one of the next sections we will describe different of these features. One example of such a feature is a dynamic order due date maintenance feature which allows to update due dates in order to refect the actual need dates.

" The population perspective is borrowed from biologists, who have developed it into an extensive, conceptually rich theory and method. The advantage of borrowing from another discipline is that much of the theoretical and methodological work has already been done. The disadvantage is that the perspective might not fit. Our view is that it has several clear advantages: 1. it offers a way to break the mental set of the existing model; 2. it already has in place many essential concepts and 3. the theoretical and methodological issues are already identified, so we have a map showing where all the difficulties and points of interest are likely to be.
Of course while organisations in changing environments have many functional parallels to organisms in changing environments, there are differences. We are fully aware that alterations and new theoretical and conceptual inventions might have to be made for the perspective to be of use in the study of organisations. Our view is that the functional parallels are strong and that the approach has much of promise and ought not to be discarded until it has been thoroughly tried" (McKelvey and Aldrich, 1983, p.108)

We believe that the functional parallels are strong enough to continue this study, but differences urge that alterations and new theoretical inventions might have to be made for MRP to be of use in hospitals. Based on the previous discussion about the arguments in favour or against the use of MRP concepts, we see two important alterations to be made:

1. The MRP mechanism and the structure of the bill of 'materials' must be changed in such a way that the planning is able to control the flow of patients through different service units (workcenters) with finite capacity.

2. Mechanisms must be built in to deal with the increased uncertainty due to the fact that a hospital is a high-contact environment and that hospital products are never completely specified at the beginning of the service delivery.

Roth and Van Dierdonck (1992) have proposed many alterations in their paper on hospital service requirements planning. We discuss and further refine these alterations in a following section.

Of course MRP is only one concept in the manufacturing planning and control theory, and several other concepts may be useful in the hospital environment. There are some suggestions to use (resource-constrained, multiple) project scheduling approaches (Smith-Daniels et al., 1988). Dr.Fleurette (see Closon, 1990, pp. 392-394) has developed PERT models for one category of DRG patients in order to find those activities which can make a project longer and to evaluate the resources necessary to intervene. Smith-Daniels et al. (1988) propose to use a modification of the Critical Path Method - Materials Requirements Planning (CPM-MRP) technique for resource requirements planning in hospitals. CPM-MRP is a resource-constrained project scheduling technique taking into account capacity resources as well as materials (Aquilano et al., 1980; Smith-Daniels et al., 1984). CPM-MRP should help to determine a schedule of activity for each patient based on existing resource limitations and allowing minimal fluctuation across facility and work-force resources (Smith-Daniels et al, 1988). The authors do not work out the proposed system. In a later section we will indicate that some of the alterations of the MRP system are project-oriented. For instance, being able to change the scheduled discharge date of a patient based on his/her progress assumes the monitoring of the progress of the patient. Patients are then considered as projects. At the other side, we do not believe that service requirements planning must occur at the level of individual activities. Hospital service requirements planning must be able to manage the patient flow across several workstations. The planning of the activities in the workstations is left to the affected department's decentralised control (Roth et al., 1992).

Roth and Van Dierdonck (1992) discuss the use of a pull-type system like kanban for planning and controlling resources and for managing the patient flow. Pull-type systems are not appropriate in non repetitive and custom-engineered environments (such as a hospital). Furthermore, kanban-type systems do not incorporate any capacity planning (Roth et al., 1992).

Finally, finite capacity loading systems are not recommended because of their poor performance record (Roth et al., 1992). Nonetheless, recent evolution in simulation tools has opened new perspectives of this kind of finite capacity loading. But these systems are still not able to manage throughput times (length-of-stay) very well.

Although the focus in this study is on MRP, the other concepts (such as project planning) may be useful to make alterations in the HSRP system to make it feasible in a hospital environment.

2.5. Performance criteria

There are two aspects related to the measurement of the performance of the introduction of a planning system in a certain environment: (1) the performance of the planning system itself as measured relative to its goals (technical performance) and (2) the performance of the planning system in the environment where it will be implemented (planning performance). Figure 2.10 shows the relationship between the two aspects of performance measurement. It clearly indicates that the planning performance is influenced by the planning decision taken, based on the output of the HSRP system. An example of such kind of decision is admission scheduling taking into account the HSRP output. In the basic experimental design, planning decisions are not included. This means that admissions are scheduled without looking at the consequences for the resource load or that the admissions are the result of a negotiation between the physician and the patient. In later experiment, we will build in those planning decisions in order to measure the planning performance.

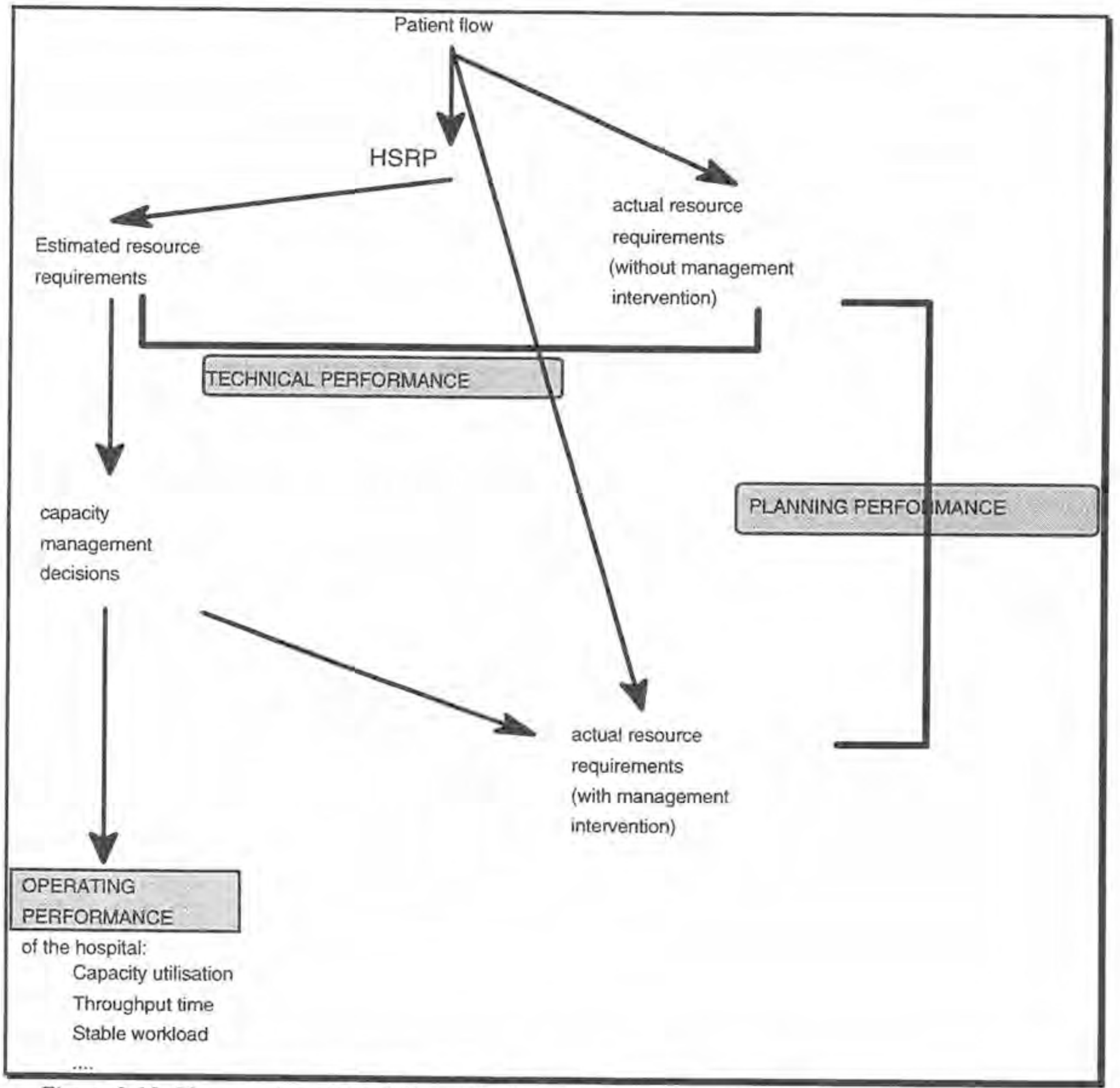

Figure 2.10. The meaning of the different kinds of performance measures

2.5.1. The technical performance of HSRP

We have already stated that the output of system for hospital service requirements planning is a time-phased resource profile showing the expected service or resource utilisation for some future period. Service requirements planning together with capacity planning decisions should help a hospital to level out peaks and valleys of resource utilisation through the projection of imbalances far enough in advance to allow resources to be varied as needed (Ritzman, 1980). In other words, the resource profile is based on a projection of imbalances. Such a projection implies the prediction of the service requirements at some future period of time. The performance of the HSRP system can then be measured as the accuracy of these predictions. The accuracy of these predictions has something to do with the difference between the actual resource requirements in a period of time and the estimated resource requirements for the same period of time (Cheng, 1987).

In the current environment of cost-containment and increasing financial responsibility, the performance of hospitals and hospital departments is monitored, and resource-use short-falls are identified (Tan et al., 1993). Changes in the financing systems give economic incentives to the hospitals to reduce the length of stay and to be conservative in resource utilisation (Rosenstein, 1994). Length of stay increasingly becomes a strategic parameter in hospital management. HSRP uses a standard (average) length of stay which is becoming a strategic parameter. In this context, it is important to have a standard which is feasible in the hospital operating environment. We define a feasible length of stay standard as a standard which minimises the deviations from the actual length of stay. This also means that the deviation between the actual discharge date and the (in the HSRP) scheduled discharge date must be minimised. This has something to do with delivery accuracy (Voss, 1980) or with earliness and tardiness (Kumar, 1993).

2.5.2. The planning performance of HSRP

The actual resource requirements are influenced by decisions made by management when one or more services are capacity-constrained. These decisions can be based on the output of HSRP. We have already indicated that service requirements planning in hospitals tries to achieve better capacity utilisation and shorter throughput times (length of stay). Capacity utilisation and length of stay must be monitored when evaluating the performance of HSRP. Better capacity utilisation does not only mean a high occupancy rate, but also less fluctuation in the daily utilisation or workload pattern. Planning decisions made with the support of service requirements planning should help to level out peaks and valley of resource utilisation. In other words, we need to measure the work load fluctuations (Shukla, 1985).

When we consider the hospital system as a queuing system, the introduction of finite capacity results in queues before the capacity-constrained unit(s). But in reality "due to the nature of health care delivery, queues generally do not form when a particular unit is fully utilised"(Cohen et al., 1980). Cohen et al. (1980) further suggest that instead of allowing queues, one of three of the following actions is taken when a unit is at full capacity:

1. The patient may be assigned to an inappropriate unit (i.e. misplacement; Dumas, 1985). For instance, a patient can be placed in intensive care although only normal care is required; or a patient is kept longer in the recovery room.

2. Other patients are relocated to accommodate the patient (i.e. bumping; Cohen et al., 1980). For instance, a patient is discharged to accommodate for another patient.

3. The patient may be directed to another hospital or sent home.

These actions follow an event which is called 'blocking' (Cohen et al., 1980). Patients can be blocked as they arrive at the hospital as well as they are transferred from one unit to another within the hospital (Cohen et al., 1980).

There is of course a cost associated with blocked transfers, i.e. the cost which results from the placement of a patient in an inappropriate facility ([25]) and the cost associated with the deviation from medically ideal treatment patterns (Cohen et al., 1980). Because it is very difficult to measure these costs, Cohen et al.(1980) suggest to use the following surrogate process measures:

1. the fraction of transfers to each unit which are blocked;
2. the proportion of each unit's patient-days which are due to inappropriate use caused by blocked transfers.

These kinds of measures are necessary in order to assure that better capacity utilisation does not lead to much blocking which is an indication of the service level (Cohen et al., 1980). Blocking does not necessarily means waiting time [26], but it introduces inconvenience for the patient. In some cases (e.g. before surgery), blocking can lead to longer throughput times (length of stay).

In summary, two kinds of performance measures are distinguished in this study: (1) the technical performance of HSRP and (2) the planning performance in the hospital. In order to find out whether HSRP fits a particular environment, these two kinds of performance measures must be related.

In a later section we will further refine these performance measures and describe the specific measures used in this study.

[25]. It is possible that this inappropriate unit does not have the appropriate equipment to take care of the patient. This certainly implies extra cost to install the equipment that the patient needs.

[26] Blocking does not mean that the process of care is stopped. It generally means that the process of care is delivered on a less than optimal place.

2.6. Summary of the problem analysis

Figure 2.11. integrates the different areas which have been explored in this study in function of hospital service requirements planning. In section 2.2. we have given an overview of the different approaches in the past to the planning of service requirements of patients. One conclusion of this review is that hospital service requirements planning requires a resource-homogeneous patient classification system (section 2.1.), insight into the capacity structure of the hospital facility (section 2.2.), a case-based resource management data (section 2.3). and a planning algorithm. We have chosen to borrow manufacturing planning and control concepts in order to develop a feasible planning algorithm (section 2.4.). In doing so, we have argued that alterations and new theoretical inventions might have to be made. Figure 2.11 also shows the different research areas which are related to the different design characteristics of HSRP: hospital operations management and operations research, manufacturing planning and control theory, and medical informatics.

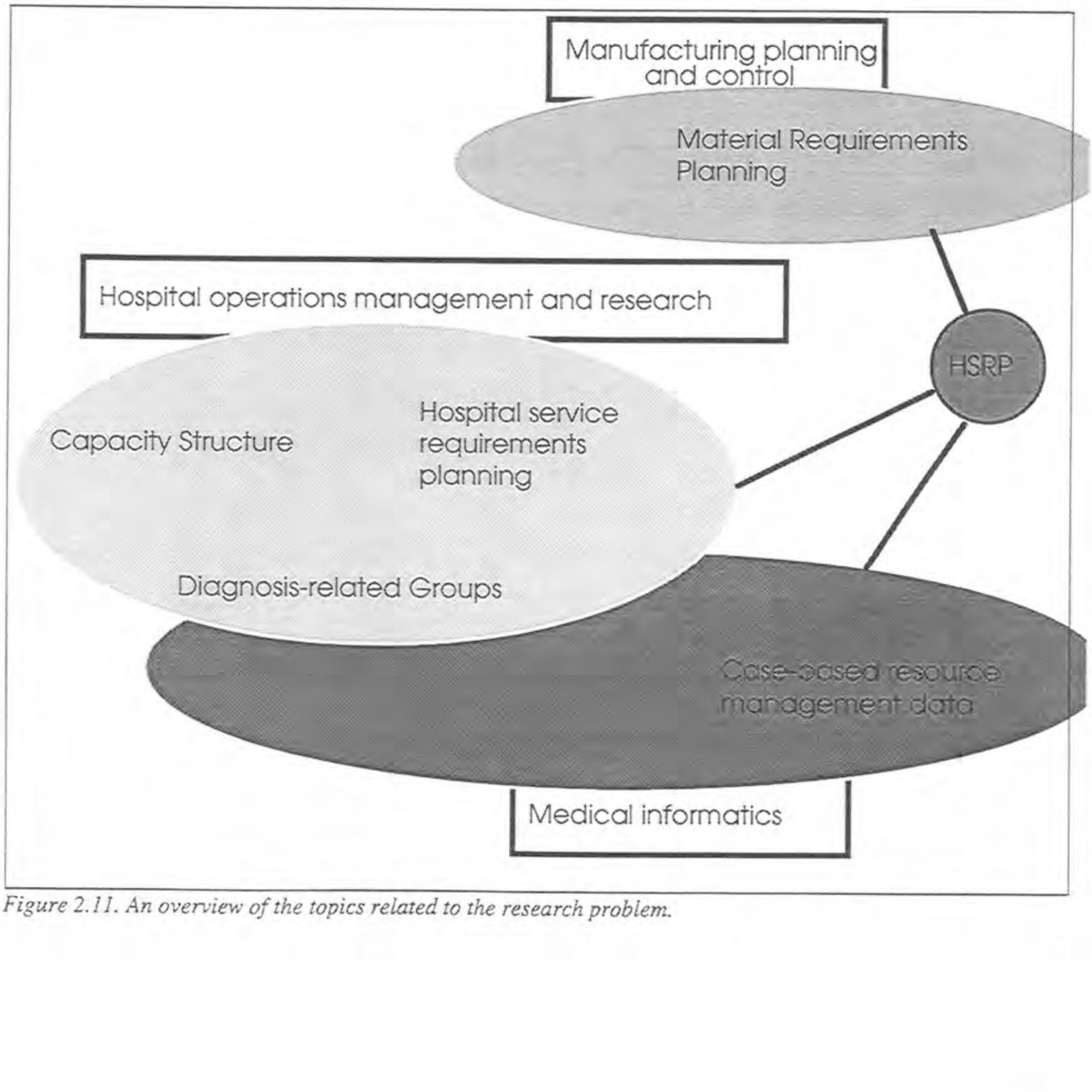

Figure 2.11. An overview of the topics related to the research problem.

3. THE RESEARCH DESIGN

In this part, we first introduce the basic research question. Then we will identify two categories of design factors: (1) the design factors of the service requirements planning system (section 3.1.) and (2) several sources of uncertainty which can be observed in the service delivery process in the hospital (section 3.2.). We will further describe strategies to deal with these kinds of uncertainty (section 3.3.). The goal is to study the impact of these uncertainty factors on the design factors taking into account different strategies to deal with uncertainty. In order to tell something about this relationship, performance measures must be developed. These performance measures are also described in this part (section 3.4.).

3.1. The basic research question

Based on the previous mentioned analogies, Rhyne and Jupp (1988) and Roth and Van Dierdonck (1992) suggest to use a MRP-like system to plan hospital resources in an integrated way. This is a 'transfer of technologies' strategy as described by Reisman (1988) where the manufacturing planning and control theory is the source discipline and the hospital service (requirements) planning is the receiving discipline (see figure 3.1.).

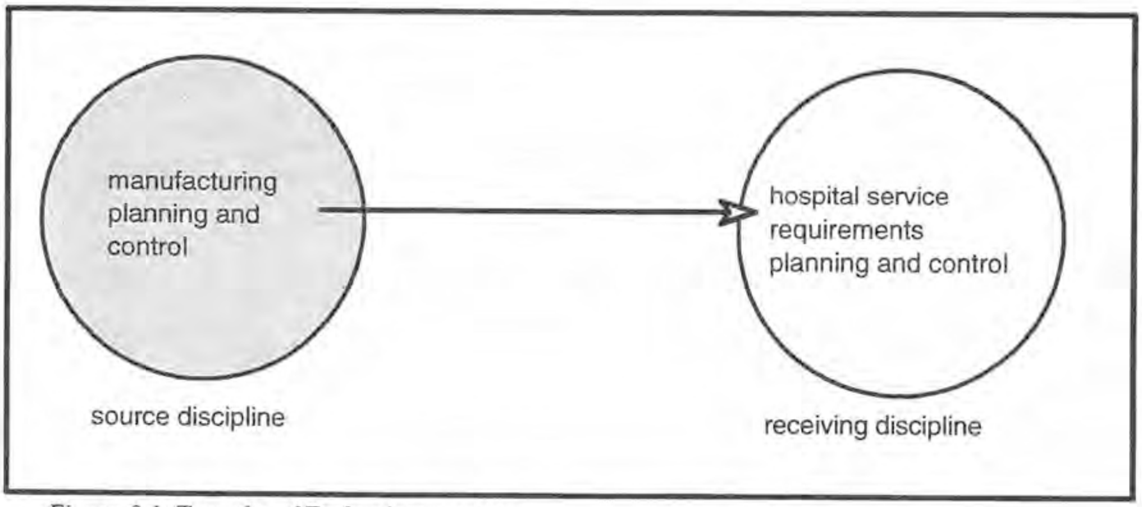

Figure 3.1. Transfer of Technology process

It is generally known that a standard MRP system is in fact a deterministic system which cannot cope with any form of uncertainty (Wacker, 1985; Bertrand and Muntslag, 1993). Of course the standard MRP system can be enhanced with other features or can be changed in such a way that it can deal with some kind of uncertainty to some extent. However, since the conceptual (MRP) model that underlies the HSRP system is itself a deterministic system, there are restrictions on the types and amount of uncertainty which it can handle [27] (otherwise so many changes or new features must be built in that the idea of technology transfer is lost).

[27] A similar reasoning can be found in Cooper and Zmud (1989).

In the manufacturing planning and control literature, a distinction is made between demand uncertainty and supply uncertainty (Whybark et al., 1976). While in the research literature on MRP a lot of attention has been paid to demand uncertainty, very little attention has been given to supply uncertainty and surely to the combined situation of demand and supply uncertainty (Brennan et al., 1993). In real-life settings, supply and demand uncertainties often occur simultaneously (Brennan et al., 1993). The study of Brennan et al. (1993) shows that there is a significant interaction effect of both uncertainties on MRP cost performance.

In the literature, two different strategies to cope with uncertainty are proposed: changing the standard MRP system in order to reduce uncertainty; developing buffering mechanisms against uncertainty (Chu et al., 1988). Many of the studies on the former strategy deal with the question whether the performance of a MRP system working in a deterministic environment is different from the performance of the same system working in a stochastic environment (see for instance Sridharan et al., 1990a; Lin et al., 1992; Zhao et al, 1993 and Lin et al., 1994).
Examples of studies on buffering mechanisms are the studies of Whybark et al. (1976) on safety stock and safety lead time and of Schmitt(1984) where safety stock as well as safety capacity are compared. Chu et al.(1988) give a comprehensive overview of the different studies dealing with these buffering strategies. These studies deal with the question whether some kind of buffering mechanism performs best in some specific situation. It seems that the kind of uncertainty (supply versus demand; quantity versus timing) and the kind of production environment (make-to-stock versus make-to-order)[28] have an important impact on the choice of buffering strategies.

Because the hospital 'production' environment is different from the manufacturing environment and because the kind of uncertainties is different (see following part), one has to look for strategies to reduce the uncertainty and to buffer against uncertainty in a such a way that the MRP-like HSRP system can be applied in the hospital environment.

The basic research question is then the following one: What is the performance of the HSRP system (based on MRP concepts) in a hospital environment taking into account the different sources of uncertainty and the different strategies to reduce or to buffer against uncertainty ?

3.2. Hospital Service Requirements Planning (HSRP): the framework

The design of the Hospital Service Requirements Planning (HSRP) system is strongly based on the Manufacturing Planning and Control Framework developed by Vollmann et al. (1992) for the manufacturing industry. A blueprint of the HSRP framework has been proposed by Roth and Van Dierdonck (1992). In the next paragraphs we shortly describe this blueprint. The HSRP system (figure 3.2.) shows three parts: a front-end, an engine and a back-end.

[28] For definitions of make-to-order and make-to-stock, see a following section.

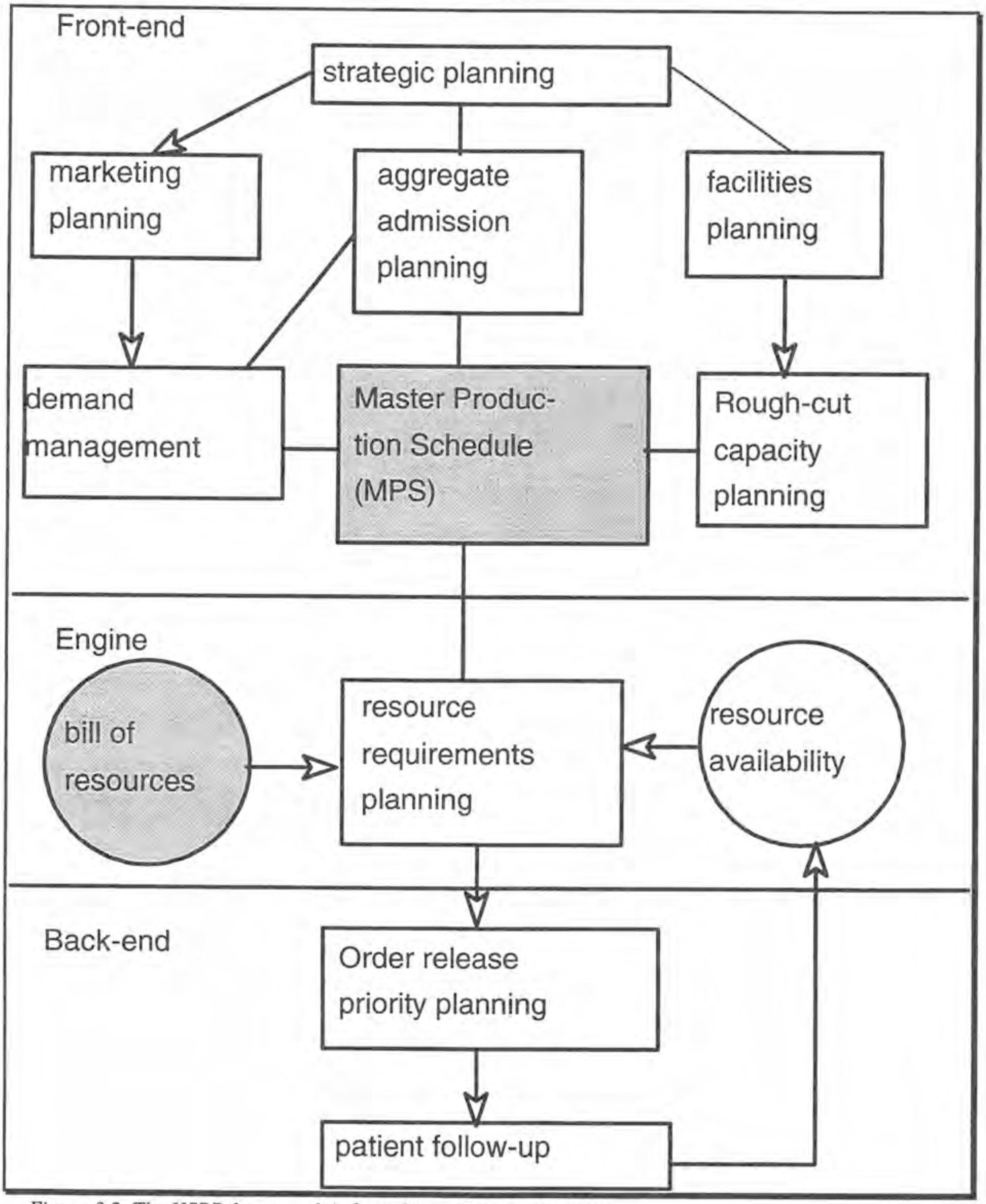

Figure 3.2. The HSRP framework (adapted from Roth et al., 1992).

3.2.1. The front-end

The front-end drives the whole system. Central to the front-end is the Master Production Schedule (MPS). In our study the MPS is an anticipated discharge schedule which is based on an algorithmic transition of planned or project hospital admissions by DRG into anticipated discharges (Roth and Van Dierdonck, 1992). Discharged patients in the MPS are based on forecasted, planned or actual admissions.

The front-end is fed by the aggregate admission planning module, the demand management module and the rough-cut capacity planning module (Roth and Van Dierdonck, 1992). In the aggregate admission planning module, an admission plan is made based on forecasts of groups or families of DRGs for a longer period of time (e.g. several months). The demand forecasting feature of the Demand Management module is an important input into the aggregate admission planning. Forecasts are based on the historical case-mix of the hospital and an analysis of the environment. The demand management module also makes forecasts on the level of discharged patients in the MPS and controls the admission process.

Master Production Scheduling should work in close interaction with the admission process of the Demand Management Module (Roth and Van Dierdonck, 1992). In this process an admission date is assigned to the patient and the patient is classified into one of the DRG categories (if the admitting diagnosis is known). Based on this admission date and on an average length of stay and on the available capacity, the anticipated discharge date of the patient can be calculated . As we will see later, the admission scheduling strategy is strongly related to the MPS process.

The purpose of the rough-cut capacity planning module is to evaluate the proposed MPS as far as critical resources are concerned. One of the techniques advocated in the manufacturing planning literature can be used (Schmitt et al., 1984).

The Master Production Schedule (MPS) is the central focus of this front-end. Busacott et al.(1994) reinforce that "*without good master schedules MRP-based work release contributes to excessive variability leading to enhanced flow times and poor service.*" That is why we discuss the MPS in more detail. In order to design a MPS which fits the hospital environments, three important MPS topics must be covered:

1. the production environment
2. the MPS method
3. the design factors of a MPS

3.2.1.1. The production environment

A different MPS procedure is used in a make-to-stock environment than in a make-to-order environment[29]. Although these distinctions are typical for the manufacturing firm, it is important to know whether the hospital environment resembles most a make-to-stock or a make-to-order environment. This distinction determines many aspects of manufacturing planning and control

[29] For a more detailed discussion of production environments, see Marucheck et al., 1986.

(and of the concepts we want to transfer from the manufacturing industry to the hospital industry).

Because services are the main component of the hospital product and services cannot be stored in a stock, a hospital cannot have a 'make-to-stock' operating environment (Bertrand et al., 1993). The operating environment in hospitals must then be compared with a 'make-to-order' environment in manufacturing (Bertrand et al., 1993). Production cannot be on forecast.

Another way to look at these different production environments is based on the degree of certainty to which the production process is known in advance. In a make-to-stock environment, the production process for each product is predetermined, while in the make-to-order environment, the production process becomes clear during production. In describing the production environment of a hospital, there is an important difference between products for which all (or many) stages of the production process can be predetermined and products for which this is not (or only partially) possible (Kremer, 1993). The point on which a diagnosis is made, is important in this context. Because our point of departure is that the diagnosis of the patient is known (see before), we consider the hospital as a 'make-to-order' environment where the process flow of the orders can be predetermined.

3.2.1.2. The MPS method

Several MPS methods are recognised based on two issues: (1) the level at which the MPS should track the product structure and (2) the focus of the MPS on material requirements or capacity requirements (McClelland, 1988). In our study, the MPS tracks the product structure at the end-item (DRG) level. In case of scheduled patients, the customer promise date is the result of an agreement between physician and patient together with a rough-cut check for operating room capacity using a 'capacity available to promise' feature (see further). The capacity available to promise feature is nothing else than a surgical schedule. The operating room capacity is assigned to the whole case-mix (and not to individual end items). By doing this, we make the assumption that the daily (or weekly) mix of products has the same capacity requirements as the historical mix of products. This means that we use a kind of rough-cut technique of planning using overall factors (Schmitt et al., 1984).

Emergency patients are scheduled on a first come first served basis independent from the operating room load.

As indicated in an earlier section, the focus in the study is more on capacity requirements than on material requirements.

3.2.1.3. Design factors of Master Production Scheduling

We have identified the following design factors:

Unit of analysis (the scope of the planning process)

Although it is the purpose to develop a planning system on the level of a hospital, we limit this study to one hospital unit, i.e. cardiac surgery. Furthermore, we have only considered 4 product lines of the case-mix of this unit: DRG 104, DRG 105, DRG 106, DRG 107.

Planning horizon

i.e. the number of future periods beyond the total production lead time for which schedules are developed in each replanning cycle (Zhao et al., 1993). The choice of the forecast window determines the MPS planning horizon (Lin et al., 1992). The length of the planning horizon must be equal or greater than the longest cumulative lead time of the products in the MPS. This means that for each product the critical path must be found. In many cases, the planning horizon is longer than the cumulative lead time because of for instance seasonal demand patterns.

In a make-to-order environment, the planning horizon is heavily influenced by how early in advance customers are willing to place their orders (Zhao et al, 1993).
In the hospital study, the planning horizon is dependent on how much time in advance a surgery can be scheduled.

Lot-sizing rule

One of the characteristics of the hospital operating environments is that no batches of patients can be made (i.e. a lot-for-lot lot-sizing rule). In other words services are provided on one-at-a-time basis (HBS, 1985). This also means that backlogs, i.e. waiting to produce an order until other similar orders are received, are not possible (Van Dierdonck, 1995).

The time period (bucket)

i.e. the time period to be used in the planning system or the planning period. Because of the relatively short cumulative lead times of heart surgery patients (± two weeks), the time period or bucket must be shorter than one week. One day seems to be a natural period.

The frequency used to revise the MPS

or the frequency for processing the time-phased records. The reciprocal of replanning frequency is the replanning periodicity (Sridharan et al., 1990). The replanning periodicity or replanning interval is the number of periods between replanning (Lin et al., 1992; Zhao et al, 1993; Lin et al, 1994).The planning frequency determines the reaction time of the MPS on changes in the environment (Van Dierdonck, 1995). The less frequently the replanning will occur, the less responsive the system will be to demand changes (Zhao et al., 1993).

The length of the demand fence or the freezing interval

or the period during which the MPS is frozen. During the freezing period the MPS may not be changed, i.e. the schedules are implemented according to the original plan (Lin et al., 1992; Zhao et al., 1993). Both the timing and the quantities are frozen (Lin et al., 1994). Discussion about time fences leads to a clear statement about which changes are handled within which period and how these changes are accommodated. Flexibility and stability are the key characteristics in this discussion (Van Dierdonck, 1995). Freezing the MPS introduces a lag in corresponding to changes.

Replanning frequency and freezing of the MPS are interrelated concepts (Chung et al., 1986). There are two extreme strategies in determining the appropriate values of replanning periodicity and freezing: (1) replanning the MPS every period using newly updated demand data ; (2) freezing the entire MPS and keep enough safety stock to cover the expected forecasts errors. Many firms use a procedure which combines the principles of these two options: replanning the MPS periodically and freezing a portion of the MPS in the planning cycle (See Lin et al., 1992). The determination of the appropriate values of replanning periodicity and freezing interval for an MPS has been an important research issue (for an overview see Lin et al., 1992; Zhao et al., 1993; Lin et al., 1994). Only some of these studies deal with an uncertain environment (Sridharan et al., 1990a; Lin et al., 1992; Zhao et al, 1993 and Lin et al., 1994). Only the study of Zhao et al. (1993) deals with a multilevel MRP system as opposed to a single level MPS system in the other studies.

Order acceptation.

Order acceptation is the function of accepting or refusing orders (Van Dierdonck, 1995). Two important logistic components of order acceptation are order specification and the available-to-promise decision. Order specification is mainly the task of physicians which must translate a customer order in work orders for more specific services and goods. The available-to-promise decision is mainly performed by the admission department and more specifically by the admission schedule.

In a make-to-order environment, the available-to-promise concept can be applied to a bottleneck capacity (Van Dierdonck, 1995). For surgical patients, operating room time is often the bottleneck capacity.

3.2.2. The engine

The purpose of the engine is to translate the planning decisions made at the MPS level into more specific decisions to make sure that necessary resources are available to execute the MPS and to perform the various activities with the right priorities (Roth and Van Dierdonck, 1992). Central to this process are the bill of resources (BOR) and the MRP mechanism. The BOR is the backbone of the planning system that helps us to translate the MPS into time-phased resource requirements using the general MRP logic (Roth and Van Dierdonck, 1992).

3.2.2.1. Structuring a bill of resources

The concept of the bill of resources is deduced from the bills of material concept. Although a bill of material originally is developed for designing, we use a bill of material for manufacturing. In this view, a bill of materials is a listing of all the subassemblies, parts, and raw materials that go into a parent assembly showing the quantity of each required to make an assembly. The bill of resources expands the traditional concept of the bill of material to include resources which may not actually be part of the product, but which are consumed in its making (Orlicky, 1975). Another view is that a bill of resources is a bill of material which include the standard manufacturing times of each manufacturing stage in the product so that product load profiles can be made (see Cheng, 1987). In this study, a bill of resources includes standard 'manufacturing' times and data on consumable (and even perishable) resources. The existing theory on bill of material can be used as a framework in the development of bill of resources (Orlicky, 1975; Vollmann et al., 1992). The structuring of a bill of resources include decisions on the number of elements and the number of levels.

The number of elements

The number of elements relates to the number of different resources taken into account in the planning system. Based on the two-part hospital production function (see section 1.1), there are two groups of resources: input resources and intermediate outputs.

Two important categories of input resources are considered based on whether the input resources are consumed during the production process or not . The first category covers materials and supplies, and the second one includes labour and capital. Labour and capital resources are characterised by their 'capacity' to generate services or products.

Resources can also be categorised on a continuum going from length of stay independent to length of stay dependent. A high correlation between length of stay of patients and resource consumption indicates dependency; a low correlation indicates independency.The bed utilisation is length of stay dependent. There are resources which are dependent on the length of stay in one kind of department and independent in another kind of department. The number of chest X-ray is for example length of stay dependent in intensive care units, but is length of stay independent in other units. The scatterplots in figure 3.3 illustrate this.

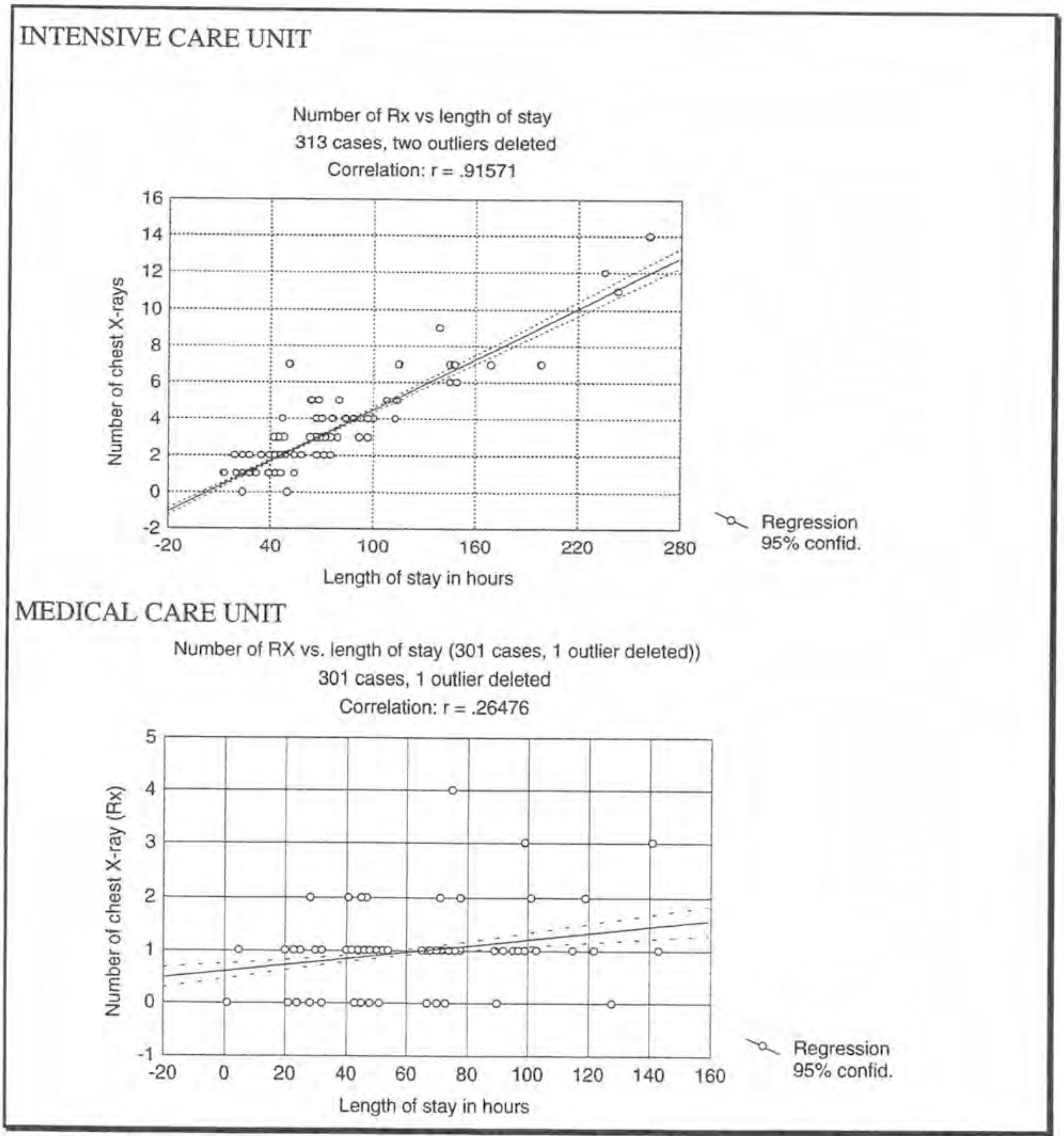

Figure 3.3. The extent to which the number of chest X-rays are length of stay dependent in a medical department and in an intensive care unit.

Because a hospital (DRG) product is made up of many different services and resources, one needs to choose those resources which are included in the bill of resources. The physician time is the most important resource because the physician is the primary leading resource who triggers all other resources (Vissers, 1994). Historically, much attention has been paid in the hospital scheduling literature at nursing services, operating room time, beds, laboratory tests and radiology procedures (see for instance Smith-Daniels et al., 1988). Most of these resources must be included in a bill of resources. Dependent on the kind of DRG, other resources can be considered as important. For instance for the treatment of cardiac surgery patients, physiotherapy is considered as very important.

It is also necessary to decide on which level of aggregation these resources are considered. Nursing services can be further specified as basic, midcare and intensive nursing care services.

In order to develop a bill of resources, there must be a way of measuring the quantity of resources required by a specific end-item. We need measures of resource use (Lichtig, 1986). A description of the resource utilisation of a DRG in a hospital can be obtained by merging the hospital's financial records or patient billing file and the patient's medical record abstract (McMahon et al., 1994):

> *" The patient's bill represents an itemised account of all the hospital services provided to the patient during his or her hospitalisation The patient's medical record abstract provides a description of his or her diagnosis, surgical procedures, and ultimately, the assigned diagnosis-related groups (DRG)."* (McMahon et al., 1994).

This merging of clinical and financial data allows to count for instance the number of chest X-rays delivered to patients of a certain DRG. McMahon et al. (1994) give the recommendation not to use the charges listed on the bill as measures of resource use because charge data are distorted by an unequal allocation of overhead costs. Nonetheless, charges are readily available and easy to use so that correcting their inaccuracies can cost more than the benefits obtained (Lichtig, 1986).

The number of levels

A level represents the completion of a step in the build-up of a product (Orlicky, 1975). A bill of material should reflect the way material flows in and out stock (Orlicky 1975), where stock is defined as a state of completion (following a stage of manufacturing). In the same way, a hospital bill of resources should reflect the way patients flow from one state of completion to another. The question is how to define a 'state of completion' or level. For a patient, a level can be defined as the completion of a stage in the course of his/her treatment. Treatment stages are defined by Roth et al. (1992) as " major natural stages, each corresponding with a major recognisable stage in the treatment process of the patient and the intervention of major departments in that process". This is very similar to a production unit as defined by Bertrand and Muntslag (1993):

> *"A PU (production unit) is an organisational grouping of resource capacities with the following characteristics:*

- internally organised such that the operations which are required to complete a given production phase can be performed independently, provided that the required materials and sources of capacities are available;

- capable of making reliable commitments with respect to the specific conditions (such as utilisation levels, throughput times, etc.) under which the operations belonging to a given production phase for a specified volume and for specified periods of time can be performed."

A bill of resources for DRG 104, DRG 105, DRG 106 and DRG 107

We have constructed a bill of resources for DRG 104, 105, 106 and 107 based on the analysis of the 364 cardiac surgery patients in our database. After interviewing the medical staff on the department, it became clear that the leading resource of this department is physician time. The allocation of physician time has been made explicit through the surgical schedule (OR time). Nursing services and beds on intensive care unit are two other (following) resources which are considered as very important.

Based on the protocol used for the treatment of these cardiac surgery patients (see figure 2.5. in section 2.2.) data on the consumption of the following resources is collected by merging clinical and billing and operational data (see section 2.3.): length of stay (LOS), operating room time (OR time), length of stay on the intensive care unit (LOS ICU), chest X-rays (Rx), electrocardiograms (ECG), echocardiograms (ECHO), physiotherapy (PHYSIO), blood (BLOOD), plasma (PLASMA) and intensive care nursing services (ICU NURSING).

The result of this analysis are the consumption profiles in figure 3.4.. The DRG 105 and DRG 107 consumption profiles are very similar. DRG 104 and 106 are more resource intensive. This was expected because the latter one includes an additional diagnostic procedure (catheterisation).

In order to transform the consumption profile in a bill of resources, we used the staging mechanism. The result is a bill of resources as illustrated in figure 3.5. for DRG 107 [30]. Three stages are recognised: the preoperative stage, the surgical stage (including a stay on the intensive care unit) and the postoperative stage. Measures of resource use are indicated using averages. For instance in the postoperative stage, each patient consumes in average 3.6 chest X-rays, 1.9 ECGs and 1.1 echo and receives 7.7 times heart revalidation. In appendix 7, a table lists the descriptive statistics of the resource utilisation in the four DRGs based on the analysis of the 364 patients. The high standard deviation as compared with the mean learns that in some cases, the variation in resource consumption is high.

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[30] To restrict the complexity of the study, we have only used the data on DRG 104 and DRG 107 patients because these DRGs are clearly different.

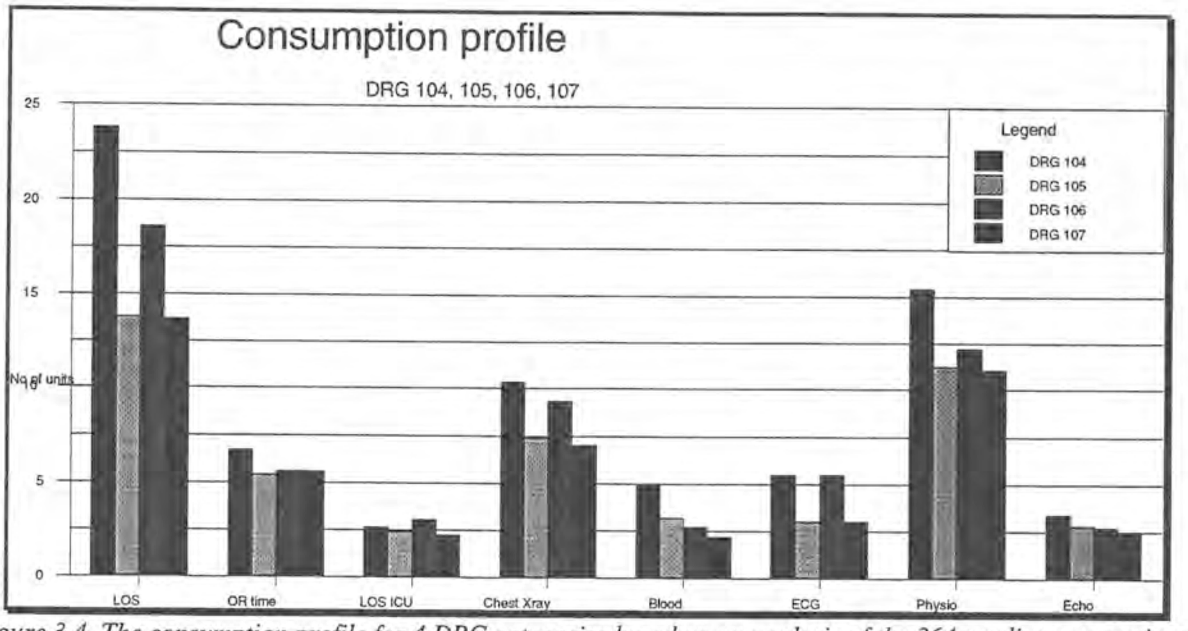

Figure 3.4. The consumption profile for 4 DRG categories based on an analysis of the 364 cardiac care patients

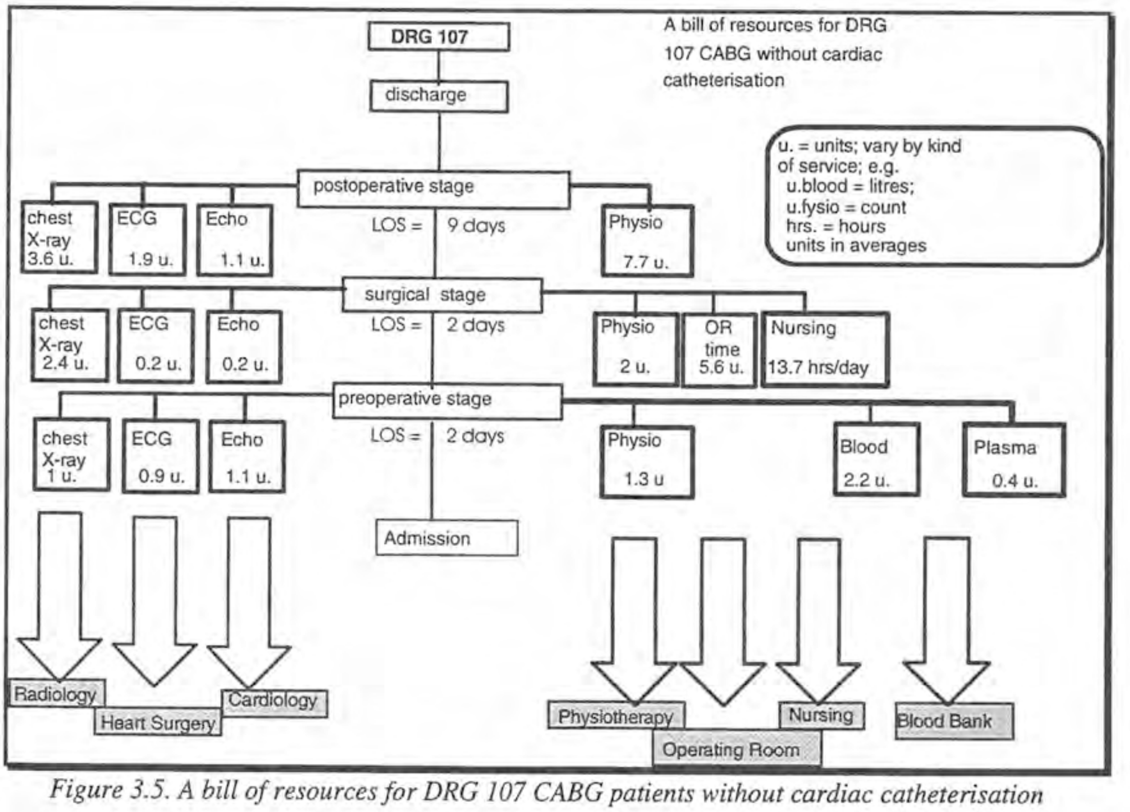

Figure 3.5. A bill of resources for DRG 107 CABG patients without cardiac catheterisation

3.2.2.2. The MRP mechanism

The MRP mechanism is a periodical explosion of the gross requirements in the MPS using the lead times (average length of stay) which are incorporated in the bill of resources. Based on this explosion, work order releases (start of each of the treatment stages) can be determined and scheduled for receipt (finish of a treatment stage) in the appropriate time periods of the related units over the planning horizon. In each of the time periods of the planning horizon, it can be determined how many patients reside in which stage or whether patients are entering a specific stage. This MRP mechanism can be considered as a Patient Flow Control mechanism which is quite similar to the Goods Flow Control as described by Bertrand and Muntslag (1993). It is concerned with the overall co-ordination for a chain of treatment stages. At this control level, the

primary process is defined only in terms of a set of treatment stages with relationships between these stages (see also Bertrand and Muntslag, 1993). Co-ordination of the stages is accomplished by releasing work orders to the production units. A work order is therefore an instruction to initiate and complete a specific treatment stage (see also Bertrand and Muntslag, 1993). A work order corresponds with a level in the bill of resources (Roth and Van Dierdonck, 1992). The more work orders (the more levels in the BOM), the more opportunities for co-ordination and intervention in the patient flow (Roth and Van Dierdonck, 1992).

Using the bill of resources, we multiply the number of patients in a certain stage on a certain period by the associated time-phased standard units of resource use (when the resource use is dependent on the LOS) or we multiply the number of patients entering a stage by non-time-phased standard units of resource use (when the resource use is independent from the LOS). By totalling up the load in each time period a capacity plan for this resource over different treatment stages for each DRG end item can be derived. The sum of the daily resource requirements on the DRG-specific capacity plans gives a time-phased resource profile (HBS, 1975).

When this preceding procedure is repeated for different resources for the same DRG end item, a product load profile is obtained. This is a time-phased demand of all constituent resources making up the finishing end item.

3.2.3. The back-end

The purpose of the back-end is to help execute accepted planned orders and follow up the progress. This module also provides feedback information for evaluation purposes. The back-end include the planning of activities in each of the major stages and the fine tuning of the arrival or availability of the various resources over the various activities. We envision this happening in a decentralised mode in the departments of a certain stage. This planning aspect does not belong to the scope of this study. The back-end completes the planning systems framework.

3.2.4. An example of the working of HSRP

Let us illustrate the working of HSRP with an example of coronary bypass patients (DRG 107). Assume a Master Production Schedule as illustrated in figure 3.6..

The first step in the classical MRP process is to translate the MPS in a so-called level 0 MRP-table. In this example, the postoperative stage is the level 0 table. The gross requirements are directly derived from the discharge column in the MPS. For instance the discharge of one patient is scheduled on day 20. This means that this patient must leave the postoperative stage on day 20. The "patients in stage" are the sum of the open orders or scheduled receipts and the planned orders. The open orders represent the patients who are currently in the postoperative stage. For instance on day 1, one patient to be discharged on day 3 is in the postoperative stage [31]. A patient is counted as 'patient in stage' from (and exclusive) the day that she/he is planned to arrive at this stage until (and inclusive) the day that she/he is leaving the stage. "Planned patients" are the patients planned to enter the stage on (the evening of) the day indicated. For instance, the patient with discharge date on day 20 must enter the postoperative stage at the evening of day 11 taking into account a postoperative length of stay of 9 days.

[31] We have used as convention that a patient enters and leaves a stage at the evening of the day that he/she is scheduled to enter or leave. That is why the patient with a discharge date on day 3 is counted in the patients in stage of day 3, but that the patient planned to enter this stage on day 3 is not counted.

MPS

Day LOS =13 days	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
DRG 107 admissions					1		1													
DRG 107 discharges	1		1									1						1		1

MRP table postoperative stage

LOS = 9 days Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Gross Requirements	1		1									1						1		1
Patients in stage	2	1	1	1	1	1	1	1	1	2	2	3	2	2	2	2	2	2	1	1
Patients planned			1						1		1									

MRP table surgical stage

LOS = 2 days Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Gross Requirements			1						1		1									
Patients in stage	0	1	1	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0
Patients planned	1						1		1											

MRP Table preoperative stage

LOS = 2 days Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Gross Requirements	1						1		1											
Patients in stage	1	0	0	0	0	1	1	1	1	0										
Patients planned					1		1													

MRP Ttable chest X-rays at the preoperative stage

0.6 units/day/patient Day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Gross Requirements						0.5	0.5	0.5	0.5											
Available	5	5	5	5	5	5	5	5	5	...										
Difference	5	5	5	5	5	4.5	4.5	4.5	4.5.	...										

Figure 3.6. An example of the MRP mechanism in HSRP

It is through these data that the linking between the various stages, and thus the co-ordination of a chain of treatment stages is performed. The planned patients (start of the treatment) in the postoperative stage correspond with the gross requirements (finish of the treatment) in the surgical stage , and the planned patients in the surgical stage correspond with the gross requirements in the preoperative stage. The time that patients reside in a certain stage depends on the standard lead-time used. This is respectively 9 days, 2 days and 2 days for respectively the postoperative, surgical and preoperative stage (see the bill of resources in figure 3.5.). These standard lead-times correspond with the average of the length of stay as measured for the group of 364 patients. As indicated earlier, a lot-for-lot rule is used.

Referring back to the preoperative stage, one can use the formal MRP-mechanism to derive from the planned patients at that stage the other resources needed at that stage. This process is illustrated for the chest X-rays needed at the preoperative stage. It has been calculated that each patient requires in average 1 chest X-ray in the preoperative stage (see figure 3.5.) or 0.50 chest X-rays per day of stay in the preoperative stage. The available row in the chest X-ray table is the number of chest X-rays that is daily produced by the radiology department. The difference row shows us over- and under-capacity. When the same procedure is repeated for different DRGs (treated in the hospital), a time-phased resource profile for the radiology department is derived in so far it concerns chest X-rays. This information (when expanded to more DRGs) is useful by itself because it basically warns the radiology of coming requests. The planning activities of the radiology itself are not done by the HSRP system.

3.3. Sources of uncertainty in the hospital environment

The goal of this section is to identify the different sources of uncertainty in the case of the 364 cardiac surgery patients. In order to find the most important sources of uncertainty in a hospital environment, we have performed a case study of the service delivery process in a heart surgery department in a Belgian hospital. In appendix 6, we show the protocol of the case- study and the different people who are surveyed. The analysis of the different databases also supports the identification of the different sources of uncertainty.

The service delivery process in the heart surgery unit and its role in an illness episode of a patient can generally be described as in figure 3.7.. In the next paragraphs, we discuss the different sources of uncertainty as indicated in figure 3.7..

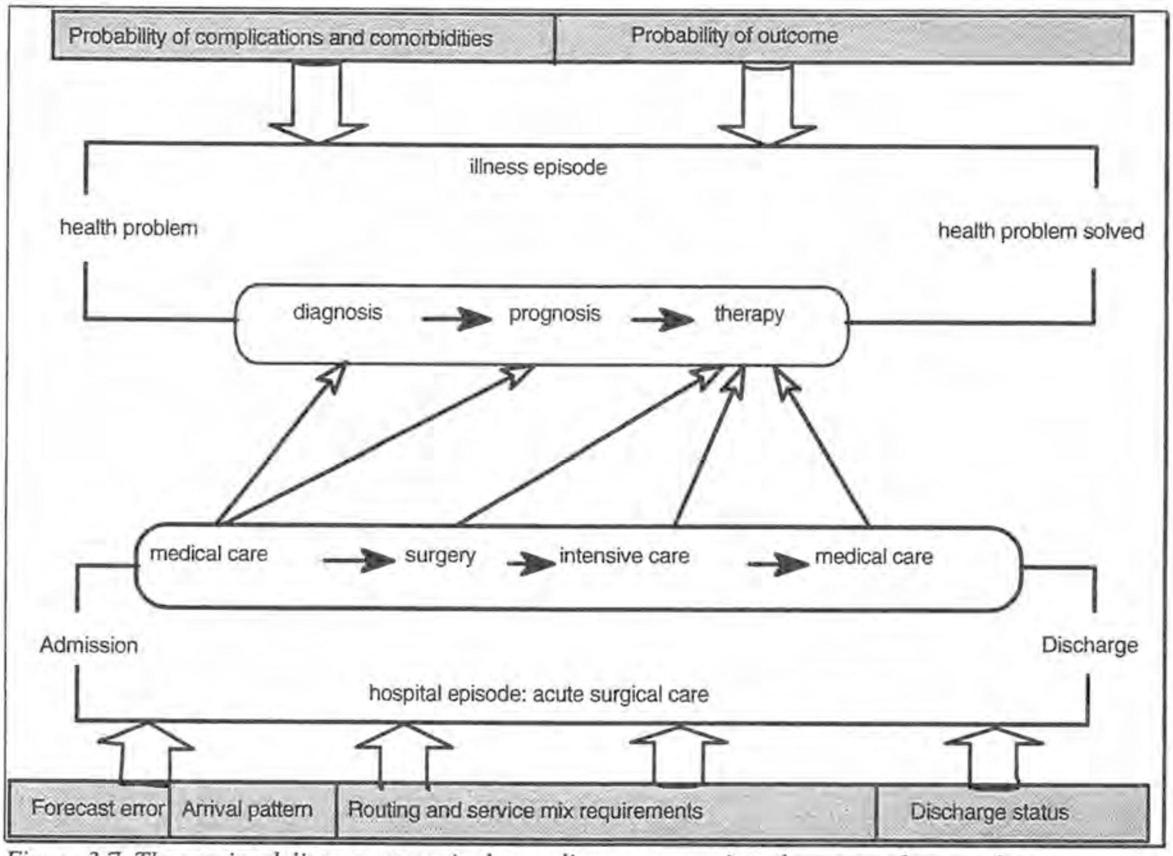

Figure 3.7. The service delivery process in the cardiac surgery unit and sources of uncertainty

A health problem is the sum of signs, complaints, physical abnormalities and pathological manifestations and so on, which the individual experiences (Hornbrook, 1982a; Bardsley, 1987). Hospital demand can be described as the generation of a patient order to solve a more or less clearly defined health problem. The first uncertainty relates to the arrival pattern of the orders. There are several ways to characterise the hospital demand pattern. Demand can be stochastic (arriving at unpredictable intervals with little notice) or deterministic (arriving at predictable intervals), stationary (arriving at a rate independent of the hour) or cyclical (with a regularly recurring variation)(Dowling, 1976; Griffith, 1992, p.89). The urgency of the orders is also very important. It is common to use three categories (Griffith, 1992, p.90): emergency, urgent and elective. The categories are defined as a continuum based on the length of delay acceptable without impairing the quality of the service. For emergency patients delay cannot be accepted while the admission of elective patients can be easily postponed. Urgent patients are situated somewhere in between. Urgent and elective patients can be scheduled.

When there is a high portion of patients for whom acceptable delay is low (urgent admissions), it is necessary to forecast the expected orders in the planning horizon. Forecastable demand provides a useful level of certainty over a given planning horizon (Lathrop, 1993), but forecasting introduces a forecast error into the system.

In the case of cardiac surgery patients, only 14 of the 364 patients are registered as emergency. This means that upon admission most of the orders are scheduled. This implies that the HSRP must incorporate an admission scheduling system and some kind of admission scheduling strategy (Milsum et al., 1973). It is important to determine how much time before admission patients are scheduled (see before).

The degree to which the health problem is clear, depends on the fact whether the diagnosis has been defined or not. A diagnosis is the assignment of a specific disease to a health problem. A disease is the medical rationalisation of the patient's condition (Hornbrook, 1982). One of the starting assumptions in this study is that by admission the diagnosis is known. This means that we study a therapeutic process where surgery is the act of intervention. Nevertheless the admitting diagnosis can change during the service delivery process due to emerging comorbidities and complications and the related new services which must be delivered. In the case of the cardiac surgery patient, the absence or presence of a catheterisation procedure during the hospital stay determines the DRG category. The probability of such a change is higher in the case of medical patients than in the case of surgical patients. In other words it is difficult in a hospital environment to identify the product at the moment an order is made. This is one of the reasons why most patient classification systems (including the DRG system) are discharge-abstract based (Thomas et al., 1991). At admission, data on specific therapies, patient's response to therapy, and the physiological effects of complications and iatrogenic diseases are not yet available (Thomas et al., 1991). In other words it is possible that patients, assigned to a certain DRG at the moment of admission, have to change from one DRG-category to another based on some events which are occurring during the patient's stay in the hospital. A change in DRG-classification implies a change in the product definition. Dilts et al. (1992) emphasise the importance of early assignment of a patient to a group. The absence of any diagnosis increases this 'product identification' problem.

Given the diagnosis, the doctor uses his knowledge of other patients with the same disease to estimate the patient's prognosis and to formulate a particular therapeutic strategy (Hornbrook, 1982a). Prognosis refers to the probable outcome of an illness (Averill, 1991). The definition of prognosis indicates another kind of uncertainty, namely the likelihood of improvement via intervention (HBS, 1985). For instance, 13 of the 364 cardiac surgery patients die during or after surgery. It is important to note that this outcome has a very important impact on the length of stay and the resulting resource consumption. Analysis of our data learns that 3 of the 13 patients (who die) have a length of stay lower than 8 days while no other patients in the group of 364 have such a low length of stay.

In the case of surgery patients, the central point in the therapeutic strategy is the surgery. This allows to identify a preoperative stage, a surgical stage and a postoperative stage. Some patients have more than one surgery during the stay. In other words, all patients do not follow the same routing through the hospital. This is even more clear when an analysis is made of the routing of patients through different departments which treat cardiac surgery patients. Table 3.1.. shows the absolute number of transitions between departments of 364 cardiac surgery patients. The hospital is in fact a network of service units (with finite capacity) (Cohen et al., 1980) and patients flow in a more or less random way through this network. The hospital can be described as a job shop (Bertrand and de Vries, 1993). This also means that it has the characteristics of a job shop. Nonetheless remark the dominant path in this case.

Table 3.1. The absolute number of transitions in the case study

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**11**	**12**	**20**
1	-	96	34	9	-	-	-	-	-	-	-	-
2	0	-	1	304	-	-	-	-	-	-	-	-
3	32	4	-	48	-	-	-	-	-	-	-	-
4	-	-	-	-	0	319	38	-	-	-	-	7
5	-	-	-	-	-	1	-	1	-	-	-	1
6	-	-	-	-	1	-	4	14	-	-	-	334
7	-	-	-	-	2	33	-	2	-	-	-	5
8	-	-	-	-	-	-	-	-	15	-	-	2
9	-	-	-	-	-	-	-	-	-	3		12
11	-	-	-	-	-	-	-	-	-	-	2	1
12	-	-	-	-	-	-	-	-	-	-	-	2

* in absolute numbers; it is not indicated where patients are coming from in the system.

1 = 2191D = Cardiology, preoperative
2 = 8140C = Heart Surgery, medical, preoperative
3 = 8325D = Intensive Care, general, preoperative
4 = 8327C = Intensive Care, heart surgery, preoperative
5 = 2191DO = Cardiology, postoperative
6 = 8140CO = Heart Surgery, medical, postoperative
7 = 8325DO = Intensive Care, general, postoperative
8 = 8327C2 = Intensive Care, heart surgery, postoperative, second attendance
9 = 8140CO2 = Heart Surgery, medical, postoperative, second attendance
11= 8327C3 = Intensive Care, heart surgery, postoperative, third attendance
12= 8140C3 = Heart Surgery, medical, postoperative, third attendance
20= Leaving the hospital

Patients with the same routing may have a different length of stay on a particular service unit. In figure 3.8., an empirical length of stay distribution of 180 patients is shown. This distribution is based on the postoperative length of stay on the medical department of the cardiac surgery unit (8140CO) of patients who have followed the same routing through different departments of the hospital [32] . Remark the skewness to the right of this distribution.

[32] Additional analysis learns that the postoperative length of stay is independent from the kind of surgery performed in this case.

Patients with same the routing and the same length of stay on a particular unit do not necessarily use the same amount of resources or do not have the same service-mix requirements. Table 3.2. shows the number of EKGs used by 35 patients. The postoperative length of stay on 8140CO for each of these 35 patients is 7 days. Furthermore these patients all had the same kind of surgery (CABG without catheterisation). In this context, it is important to make a difference between resources which are length of stay dependent and resources which are (partially) length of stay independent.

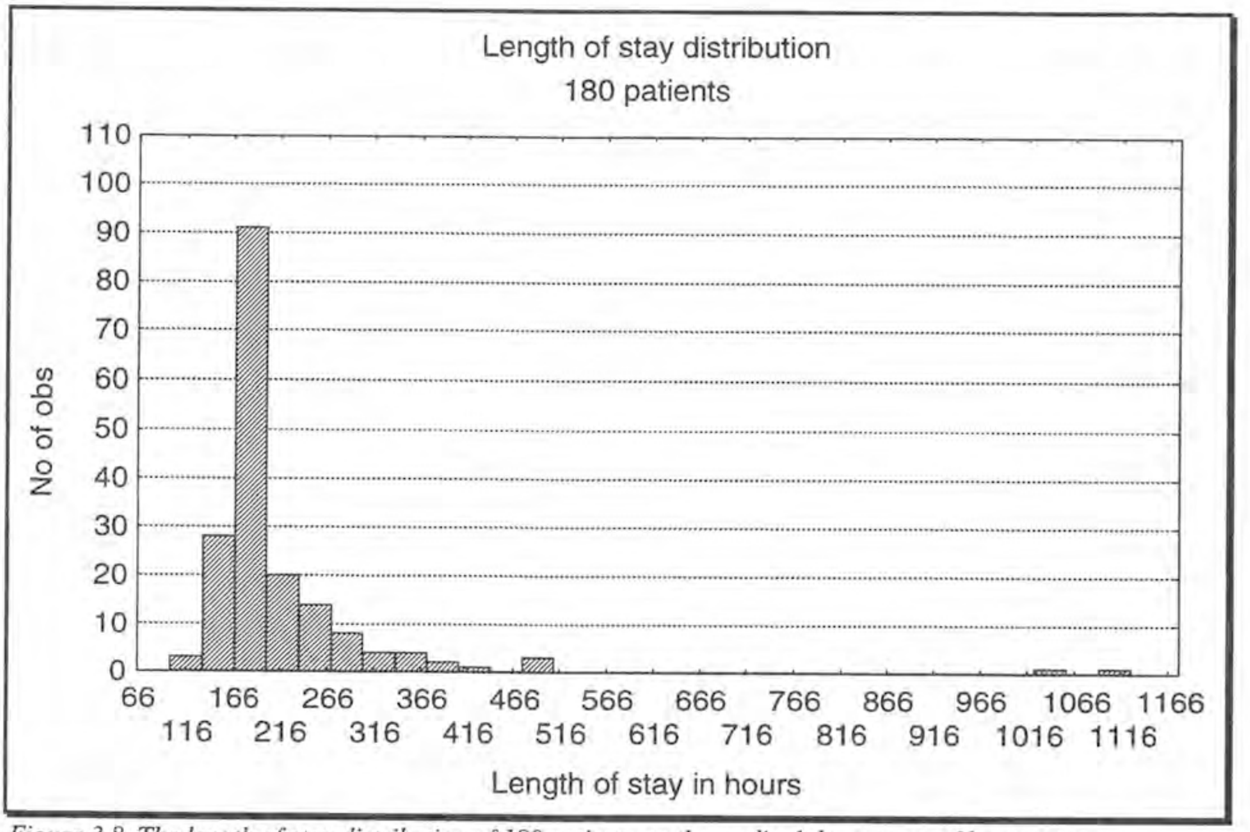

Figure 3.8. The length of stay distribution of 180 patients on the medical department of heart surgery, postoperative (8140CO); patients with the same routing (8140-8327-8140CO)

Table 3.2. The number of EKGs consumed by 35 CABG patients on the medical department of the cardiac surgery unit (8140CO), postoperative. The patients have the same kind of surgery and follow the same routing through the hospital.

Number of EKGs	Number of observations
0	7
1	5
2	20
3	2
4	1
Total	35

An order is finished when the health problem is solved. In an acute care setting, this coincides with the discharge of the patient from the hospital. In other words, the promise date on the patient order is the discharge date. It is this date which is used in the master scheduling process. The promise date is an expected target date for the customer's order (McClelland, 1988). To establish the promise date, we use an (historical) average length of stay or the experience of the physician. The promise may eventually not be met because of a longer or shorter than average length of stay on one or more departments. The percentage of promises kept, i.e. customer orders delivered on time is a prominent service criteria (see further)(McClelland, 1988).

Uncertainty in the routing, the length of stay and the resource utilisation (service mix requirements) is a consequence of the typical service characteristics of the hospital delivery process: simultaneity of production and consumption (Chase, 1978), customer processing (Lovelock, 1992), customisation (Morris et al., 1987) and the high-contact environment (Smith-Daniels et al., 1988).

The sources of uncertainty typically taken into account in admission scheduling models are the arrival pattern of patients, the patient length of stay and the patient service mix requirements (Smith-Daniels et al., 1988).

In the manufacturing planning and control literature, a distinction is made between demand uncertainty and supply uncertainty (Whybark et al., 1976). In hospitals, because patients are part of the production process, demand and supply uncertainty cannot be distinguished very well. For instance variations in the length of stay of patients are caused by practice patterns of physicians (supply) as well as by the severity of illness of the patient (demand). The due-date (discharge date) is not specified by the customer, but largely by the physician. In fact the dichotomy demand-supply does not describe very well uncertainty in the hospital environment. In looking for a better framework, we used the distinction introduced by Bertrand and Muntslag (1993) for engineer-to-order situations: uncertainty of product specifications, the mix and volume uncertainty of demand and process uncertainty (Bertrand and Muntslag, 1993).

Uncertainty of product specification covers two problems: (1) identifying the right product (DRG) category to which a patient belongs and (2) specifying the different stages of the treatment process. The former problem is about patient classification while the latter problem deals with the statement of the treatment stages in a bill of resources. The uncertainty in outcome can also be considered as an aspect contributing to the uncertainty of product specification. Mix and volume uncertainty of demand deals with the problem of emergencies and the forecast error. The process uncertainty is the result of the complexity of the job shop like structure of the hospital operations with different routing and varying operation times and service requirements (Bertrand and Muntslag, 1993). In the specific case of the cardiac surgery patients, we did not detect any other source of uncertainty.

3.4. Strategies to deal with different sources of uncertainty

3.4.1. Uncertainty of product specification

The first problem in product specification is the identification of the right product. Sometimes the patient is assigned to the wrong DRG category. We call this factor '**classification error**'.

The are different ways to deal with this problem of product specification:

1. the identification of early product identifiers such as sex, age and reason for admission (see Dilts et al., 1992);

2. the use of more aggregate product definitions by grouping DRGs in 'families'. For instance, for Adjacent DRGs (ADRGs) complications and comorbidities do not lead to shifts from one group to another as long as the principal diagnosis does not change. On the level of a Major Diagnostic Category, there may be even changes in diagnosis as long as the same organic system is involved.

3. the use of forecasted instead of planned patients. In this case the accuracy of the forecasting technique is crucial.

4. more frequent replanning. As seen before, this design factor of the MPS allows to be more responsive to changes in the environment as soon as more information becomes available.

The task of specifying treatment stages for an identified end-item is generally more difficult for medical cases than surgical cases (Lathrop, 1993). For surgical patients, at least three stages can always be distinguished: the preoperative stage, the surgical stage and the postoperative stage. To identify the stages we have observed the physical transfer of patients from one unit to another. The link between treatment stages and physical transfer is a critical assumption for the so-called progressive patient care facilities (Cohen et al., 1980). Coronary care patients are generally considered as such kind of progressive care patients where the relevant stages are coronary care, post-coronary care, intensive care, medical care, surgical care and ambulatory care (Thomas, 1968; Cohen et al., 1980). Because of lack of sufficient data, we are not able to identify this more detailed sequence of stages.
For medical cases, the task of specifying stages is much more difficult, but it will be sustained by the development of clinical practice guidelines (Nash, 1993) and clinical pathways (Zander,

1992). Because we only deal with surgical cases in this study, we do not further elaborate on this subject.

3.4.2. Mix and volume uncertainty of future demand

In this study orders are planned. There is no forecasting. The only uncertainty factor is then emergencies. This means that future demand in any time bucket is known with certainty unless there are emergencies. Emergencies are patients giving less notice of admission than the planned lead time.

The typical way in hospitals to deal with emergency admissions is to maintain slack capacity (Smith-Daniels et al., 1988; Griffith, 1992). Slack capacity is a strategy which reduces uncertainty but at a cost of decreased performance in terms of efficiency (Galbraith, 1973). A HSRP system must allow to reduce the amount of slack capacity by better tracking the capacity needed for the scheduled patients.

3.4.3. Process uncertainty

Process uncertainty deals with the estimation of the type and amount of resources that will be required (Bertrand and Muntslag, 1993). There are two sources of process uncertainty in hospitals (Smith-Daniels et al., 1988): patient length of stay and patient service mix requirements.

In MRP terms, the length of stay uncertainty is a lead time uncertainty. Very little attention has been given to lead time uncertainty as a research variable in MRP (Brennan et al., 1993). Grasso et al. (1984) study the impact of uncertainty in the lead time of purchased parts. Huang et al (1985) investigate uncertainty in processing times alone as well as in combination with demand variability. Brennan et al. (1993) study the behaviour of an MRP production system in the presence of uncertainties in lead times and demand due to unpredictability in supplier/customer behaviour and/or process uncertainty. Cheng (1987) studies the impact of uncertain operation times on the accuracy of the capacity requirements plans generated by a MRP system. All these studies found that lead time uncertainty has a significant impact on the performance of the MRP system. According to Cheng (1987) the accuracy of a capacity plan is a quadratic function of the degree of variation in operating times and is significantly affected by the product demand. Lead-time uncertainty has also an impact on the demand during the lead-time (Bagchi et al., 1984).

A standard MRP system works with standard lead times. We are going to use the average length of stay as a standard (planned) lead time. Lead-time uncertainty means that the planned lead time may differ from the actual lead-time (Buzacott et al., 1994). In order to deal with lead-time uncertainty, we are going to track a patient while he/she is flowing through a network of hospital units. At some points during the flow, the actual lead time (up to this point) will be compared with the planned lead time (up to this point). This allows to reschedule a patient's discharge date whenever important differences are detected. This kind of rescheduling can be described as 'dynamic open order due date maintenance' (Penlesky et al., 1989).

Because lead-time uncertainty is a timing uncertainty, it is suggested that safety lead-time can also be an appropriate strategy to deal with it. (Whybark et al., 1976).

The uncertainty about the patient's service-mix requirements is related to the question which resources and how much resources are used. In the section on structuring the bill of resources, we discussed the question of which resources must be included.

One problem with specifying the quantity of resources required by a specific end-item, is that the relationship between the quantity of resources required and the DRG product is not fixed with certainty. This is a consequence of the within DRG resource heterogeneity (Rosko, 1988). There are different strategies to deal with this kind of uncertainty (see also Roth et al, 1992):

1. The specification of requirements in a bill of resources must be based upon parameters of sampling distributions, including the means and variances. Roth et al. (1992) believe that means are sufficient for strategic and medium-term planning, but for short-term planning variability must be taken into account.

2. The development of a generic bill of resources.
" .. in hospitals generic bills of resources can be constructed for each DRG. Upon arrival, or diagnosis, a patient's treatment plan becomes the specific bill of resources which has the potential for real time management of patient care"(Roth et al., 1992).

The concept of generic bill of resources is related to the concept of critical or clinical pathways (Zander, 1992). Clinical pathways show the day-to-day process of health care delivery for a standard patient with a specific diagnosis (Rosenstein, 1994). When measures of resource use are added to these critical pathways, they can be used as generic bill of resources.

3.5. Conclusion

Figure 3.9. summarises the research design of this study. Using MPS and MRP concepts from the manufacturing industry environment and using the DRG patient classification system, a Hospital Service Requirements Planning system was conceptualised. This kind of conceptual framework requires validation that the transferred concepts are useful and meaningful (Meredith, 1992). This study tries to bring some validation taking into account the differences between the hospital and manufacturing environment with an emphasis on sources of uncertainty.

Different sources of uncertainty in a hospital environment are recognised and classified as production specification uncertainty, mix and volume uncertainty of future demand and process uncertainty. Furthermore several strategies to deal with these uncertainties are developed. The strategies are categorised as 'strategies to reduce uncertainty' and 'strategies to buffer against uncertainty' (Chu et al., 1988). In terms of Galbraith (1973), buffer strategies reduce the need for information processing and reduction strategies imply an increased capacity to process information.

The experimental design factors will be made up in such a way that different strategies to deal with uncertainty are built into the HSRP system using some of the MPS design factors.

In order to test the impact of several of the design factors on the performance of the HSRP system, we will perform a simulation-based experimental design. The ultimate goal is to find those factors which determine the performance of HSRP in different hospital environments. We are looking for the major dimensions that should be considered in follow-up research. This is exploratory research (Emory, 1985).

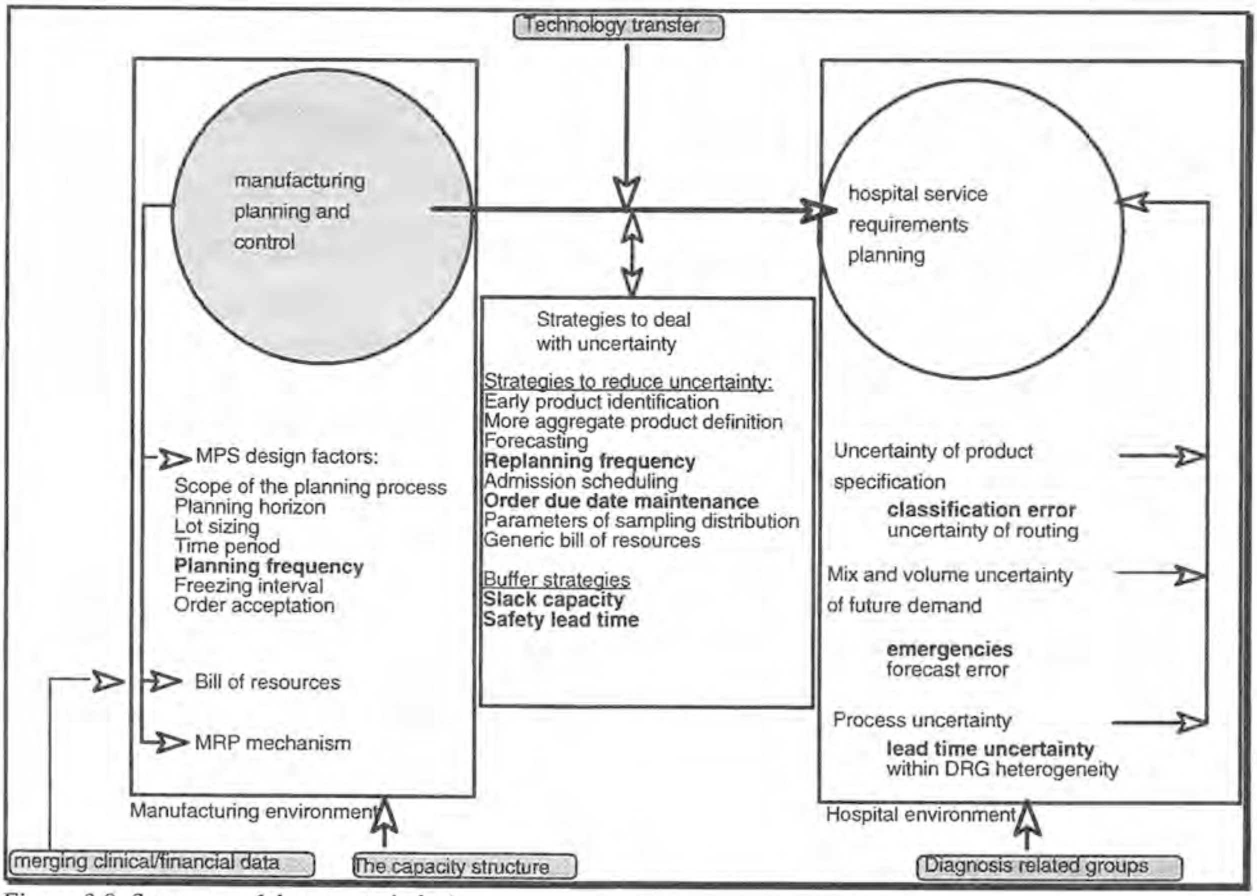

Figure 3.9. Summary of the research design.

4. SIMULATION-BASED EXPERIMENTAL DESIGN

The research strategy in this study can be described as a simulation-based experimental investigation. In order to perform an experimental investigation, an experimental design must be set up. The first task in an experimental design is to identify the different factors and responses. In the next paragraph, we describe these factors and their levels. Then we will make an overview of the different performance measures which will be used as responses in this study. The different factors and the responses are linked through hypothesis statements. In a next stage, an experimental design strategy will be selected and the design matrix is shown. Finally the simulation model used in this experimental design is described.

4.1. Factors and factor levels

There are different categories of factors: (1) sources of uncertainty, (2) HSRP design factors and (3) strategies to deal with uncertainty (not HSRP design factors). Some of the factors presented in this section can be classified in category (2) and (3). For instance planning frequency is a HSRP design factor and can also be used as a strategy to deal with uncertainty. That's why we have further specified the third category of factors as being 'not HSRP design' factors.

4.1.1. Factors related to sources of uncertainty

Classification error

This error creates a product specification uncertainty. It is introduced by a percentage of patients which are classified in the wrong DRG before or at admission. This means that these wrongly classified patients are treated as (e.g.) DRG 104 patients in the HSRP system while they flow through the simulated system as DRG 107 patients (and in the other way). The wrong classification is only detected after discharge when the discharge abstract is available. This means that a strategy of dynamic order due date maintenance does not add any value to identify a wrong classification (in this study).

The main difference between the two patient groups is the length of the preoperative stage[33]. The length of the other stages and the consumption of specific resources during the stages is quite similar in both DRG groups. In other words substitution in the resource consumption between both patient groups is highly probable and can reduce any negative effect of classification error.

Uncertainty of routing

This factor is introduced by the transition probability matrix. In the current study, uncertainty of routing is not used as an experimental factor. This means that the transition probabilities and the underlying length of stay distributions do not change in the different experimental treatments.

[33] In the final model, only two patient categories (DRG 104 and DRG 107) are modeled.

Emergencies

The number of emergency patients is a factor of demand uncertainty. It is specified as a percentage of total patient orders. Emergency patients flow directly through the hospital system at the moment that orders are created. Their discharge notice is equal to the current time increased with the planned lead time.

Forecast error

As indicated earlier, we do not use forecasting in this study. Consequently, forecast error is not introduced as an experimental factor.

Lead time uncertainty

This factor of processing uncertainty is built in by varying the standard deviation of theoretical distributions (see section 4.5.4.2). These distributions describe the length of stay of patients in four high-volume cells of the transition probability matrix (describing the probability of transition of patients from one department to another in the hospital system).

Within DRG resource heterogeneity

This factor of processing uncertainty is introduced by using empirical distributions of the consumption of specific resources in different departments. Although this kind of uncertainty is built into the model, it is not used as an experimental factor.

Two kinds of resources are modelled: bed resources as an example of a resource which is length of stay dependent and chest X-ray (radiology) as an example of a resource which is dependent on the length of stay in some departments and which is length of stay independent in other departments.

4.1.2. HSRP design factors

The following experimental factors are related to the design of the HSRP and are introduced as experimental design factors: planning frequency, freezing interval, dynamic order due date maintenance, safety lead time and planning horizon.

Planning frequency

This factor is introduced by means of the replanning periodicity which has been described as a MPS design factor. The replanning periodicity is the number of periods between replanning.

Freezing interval

The freezing interval in this study is equal to the replanning periodicity. When the planning performance (and not the technical performance) of HSRP will be tested, freezing becomes a more important design factor because freezing determines the stability of the MPS. Stability is important when one wants to take decisions based on the HSRP output.

Dynamic order due date maintenance

In the current state of the model there is only one point during the flow of patients where the actual state of the patient is compared with the planned state. This point is just before the entry of the surgical stage or just after the preoperative stage. The actual preoperative length of stay is compared with the planned preoperative length of stay (standard lead-time) and the difference (if larger than one day) is used to reschedule the discharge date in the MPS. We remark that the main difference between the patient categories (DRG104 and DRG107) is the length of the preoperative stay.

Dynamic order due date maintenance can be considered as a first step to admission monitoring with the goal of scheduling admissions in such a way that the capacity load fluctuations on different units are minimised (Shukla, 1985). Because there is no feedback after rescheduling the discharge date to the scheduled surgery date, this monitoring is not yet built in our system.

Safety lead time

This factor is introduced by adding a certain amount of lead time to the planned mean lead time of a DRG category. We are going to increase this planned lead time with a percentage of the DRG-specific standard deviation of the length-of-stay distribution (because the planned lead time or length of stay of each DRG is different).

Planning horizon

The length of the planning horizon is related to the degree of demand uncertainty and the length of the replanning periodicity (Sridharan et al., 1990; Zhao et al., 1993). The longer the planning horizon, the higher the forecast error of demand. In this study forecast error is not included as a design factor and emergencies do not have any relationship with planning horizon.
The length of the planning horizon has also an impact on the stability of the schedule [34], although the relationship is complex and must be considered in conjunction with freezing interval and the lot-sizing method used (Sridharan et al., 1990). Freezing interval and lot-sizing method are not included as experimental factors in this study.

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[34] A stable schedule is one that does not change with time as additional requirements data are added to the planning horizon (Sridharan et al., 1988).

The planning horizon in this study must be at least equal to the maximum value of the standard lead time . If the lead-time of a particular patient is greater than the planning horizon, his/her resource requirements for the current day are not included in the MRP explosion. The standard lead-time in this study is the average length of stay for a specific DRG group, i.e. all patients in the same DRG have the same (average) lead-time. [35] Some preliminary runs with the model show that this maximum cumulative standard lead time is approximately 20 days. We use a planning horizon for the MRP explosion of 35 days which is much more than the cumulative longest standard lead time in order to account for random behaviour.[36] A longer planning horizon also permits the use of a longer planning periodicity.

There is an important reason to limit the length of the planning horizon. The longer the planning horizon, the greater the scope of the MRP explosion, the more computer time is needed to work through the MRP explosion.

Other MPS design factors are not included in this study. Lot-sizes is not a design factor in this research. In fact a lot-for-lot rule with a batch of one is used. The DRGs are used as the unit of analysis. A time-period (bucket) of 1 day (24 hours) is used in the model. Too many model changes must be made to introduce time-period as an experimental factor. Order acceptation is implicitly built in by simulating the negotiation process between the physician and the patient in order to determine the admission date. In later stages of the research when planning performance is evaluated, it should be possible to model the available-to-promise concept.

Dynamic order due date maintenance, planning frequency and safety lead times are also factors used in strategies to deal with uncertainty.

4.1.3. Strategies to deal with uncertainty (not HSRP design factors).

In order to limit the scope of the experimental design, we had to be selective in our choice of non-HSRP design factors which model strategies to deal with uncertainty. There are two important not-HRSP related strategies which are dealt with in this study: (1) safety capacity and (2) admission scheduling.

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[35] It is important to note here that the standard lead time is determined in the simulation model itself for each simulation run. So we have taken into account the impact of random behavior on this standard leadtime. That's why we have performed some preliminary runs with the simulation model to determine a planning horizon which is sufficient large in every treatment of the experiment (see further).

[36] Certainly in the case of dynamic order due date maintenance, the computertime strongly increases. In later experiments, planning horizon can be introduced as an experimental factor.

Safety capacity (Capacity limits)

To introduce this factor, we have used the concepts of infinite and finite capacity. The difference between infinite and finite capacity is based on whether or not blocking occurs. In the case of infinite capacity, there is sufficient (safety) capacity to deal with any kind of demand (blocking does never occur). In a hospital environment, this assumption of infinite capacity is not necessarily false. By keeping a high level of capacity (e.g. beds) or by making some resources extremely flexible (e.g. nurses), a situation is created which resembles infinite capacity. In the current environment of health care cost containment, this strategy of reducing uncertainty (Galbraith, 1973) will be not acceptable any more. Finite capacity will be the rule. In the model finite capacity is introduced by limiting the number of available beds on the intensive care unit. That's why we often use the term 'capacity limits' to define this factor. By limiting the ICU bed capacity, blocking can occur at the end of the preoperative stage. There are different strategies to deal with blocking (Cohen et al., 1980). We are going to use a misplacement strategy in which patients are kept longer (than necessary) in the preoperative departments. The 'dynamic order due date maintenance' feature gives the opportunity to reschedule the discharge date of patients when long blocking times occur. In this way the MPS can take into account the effects of finite capacity.

Admission scheduling

In the literature review, we have indicated the role of admission scheduling in service requirements planning. Admission scheduling is common practice in many hospital. If we want to evaluate the technical performance of HSRP in the current hospital environments, admission scheduling strategy must be considered as a factor because it is part of this environment.

In the base experiment, we consider admission scheduling as a process of negotiation between the physician and the patient without taking into consideration resources. Such kind of scheduling strategy implies that each physician schedules his/her own patients without taking into account the scheduled patients of other physicians. We have observed in some Belgian hospitals that this kind of individual scheduling occurs. In the case of the heart surgery department, we have observed that this negotiation process is very important in scheduling patients. To model this strategy, we use empirical data on the length of time between the date of catheterisation and the real admission date for scheduled patients in the database. We assume that this date is not influenced by capacity availability.

The proposed admission scheduling strategy does not take into account resource availability because an admission schedule which is based on resource availability is in fact an application of service requirements planning. This kind of admission scheduling inhibits the objective evaluation of the technical performance of HSRP because of interferences between two planning systems.

Admission scheduling based on resource availability is an interesting planning application of HSRP. In further experiments, the planning performance of HSRP can be evaluated for those situations where admission scheduling is based on the HSRP output.

Table 4.1. summarises the different factors and their factor levels. This is only a selection of some of the factors identified in figure 3.9. in the previous part. There are two important reasons to be selective: (1) too many design factors are leading to a too complex model which cannot be analysed in the appropriate way; (2) every additional design factor requires additional modelling and programming, increasing the complexity of the program without being sure that a basic model of HSRP is feasible.

Table 4.1. also learns that some of these factors are quantitative while other factors are qualitative. Some of the factors are controllable. This means that management can have an impact on the level of these factors.
In determining the levels of the different factors, we have used the following arguments. In the case of cardiac surgery patients, the classification error and the number of emergencies are very low. So we decided to choose 0% as the first level. We did have no objective figures to determine what could be a high level of classification error. The 25% level for emergencies has been determined based on data of the University hospital. In the nine first months of 1990 the hospital registered that 26% of all admissions[37] are emergencies (De Moor et al., 1991). The first level of lead-time uncertainty reflects the current mean and standard deviation of the length of stay distributions in the cardiac surgery department of the University hospital. The second level of lead-time uncertainty is determined in such way that the coefficient of variation (standard deviation/mean) is approximately one for the different length of stay distributions of the high-volume matrix cells [38]. Table 4.2. shows these high-volume matrix cells and the means and the standard deviations of their distributions. The levels of planning frequency have been chosen in function of natural periods (1 day, 1 week). The finite capacity level has been chosen in such a way that an average bed occupancy of 80% is obtained. It is generally accepted that an approximately 80% occupancy level allows for moderate slack. Preliminary experiments with the model help to determine the number of ICU beds which agree with a 80% occupancy level. Finally the levels of safety lead-time are the same as the levels of lead-time uncertainty.

[37] These figures are based on the whole patient population.

[38] These are cells in the transition probability matrix. A cell is defined by the current department where the patient resides and his/her destination in the next step. Patients which remain in the same department, but with different destinations after the current stay are classified in different cells.

Table 4.1. Design factors and factor levels

	FACTOR	Quantitative factor ?	Controllable factor ?	Factor levels[39]
1.	classification error	Yes	Partially	level 1: 0% (no) level 2: 25% (yes)
2.	% emergencies	Yes	No	level 1: 0% (no) level 2: 25% (yes)
3.	lead time uncertainty	Yes	Partially	level 1 = 1 * calculated stdev of length of stay distribution (low) level 2 = 1.25* calculated stdev of length of stay distribution (high)
4.	planning frequency	Yes	Yes	level 1: 7 day (low) level 2: 1 days (high)
5.	dynamic order due date maintenance	No	Yes	level 1: No due date maintenance(no) level 2: due date maintenance (yes)
6.	safety capacity	Yes	Yes	level 1: infinite capacity or no capacity limits (no) level 2: finite capacity. with moderate slack (5 ICU-beds and 80% occupancy) (yes)
7.	safety lead time	Yes	Yes	level 1: 0% * calculated stdev of length of stay distribution (no) level 2: 25% * calculated stdev of length of stay distribution (yes)

Table 4.2. The mean and the standard deviation of the length of stay distribution of 4 high-volume matrix cells.[40]

Location	Mean	Standard deviation
Matrix cell (1,2) (Cardiology preoperative)	138	109
Matrix cell (2,4) (Heart surgery, medical, preoperative)	55	44
Matrix (4,6) (Intensive care, heart surgery)	58	56
Matrix -(6,20)(Heart surgery, medical, postoperative)	245	152

[39]The (no), (yes), (low) or (high) indicate how these different levels will be named in the subsequent analysis.
[40] Matrix cell (1,2) is the cell on the first row and the second column in the transition matrix which is shown in table 3.1. in section 3.3. Sources of uncertainty in the hospital environment.

4.2. Performance measures (responses)

In the first part, we made a distinction between technical, planning and operating performance measures. We now further specify the different performance measures.

4.2.1. Technical performance measures

The accurate prediction of resource requirements

An important aspect of the technical performance of the HSRP system is the accuracy of the predictions of resource requirements. The accuracy of these predictions has something to do with the difference between the actual resource requirements in a period of time and the estimated resource requirements for the same period of time. The following performance measure will be used:

$$\text{MPDi} = \frac{\sum_{k=1}^{p} \left| \frac{A_{ik} - E_{ik}}{E_{ik}} \right| \times 100}{p} \qquad (4.1)$$

with

Aik = the actual resource requirements in period k of resource i
Eik = the estimated resource requirements in period k of resource i
i = different kind of resources.
p = the number of periods

A similar performance measure has been used by Cheng (1987). It is described as the mean percentage deviation and is used as an overall performance measure of the accuracy of the plan. If for instance MPDi is 10%, the actual requirements deviate in average 10% from the estimated requirements. In fact, this measure is also known as mean absolute percentage error (MAPE), one of the typical forecasting-error measures (Lee et al., 1987).

The accurate prediction of the discharge date (due date)

The previous performance measure does not tell anything about the delivery performance in the system (Voss, 1980). Delivery performance can be measured as the difference between the scheduled and the actual discharge time of the patient and is generally considered as a performance measure of customer service (see Hall, 1991). Voss (1980) proposes several measures of delivery accuracy. Although delivery performance is until now not routinely used as a performance criterium in a health care environment, we believe that prospective budgeting systems and patient-focused care will bring along an increased attention for delivery performance.

Voss (1980) makes a distinction between historical and current lateness. Lateness or tardiness is the difference between the promised delivery (discharge) date and the actual delivery date. In historical measures of lateness, we measure against the original promise date. The original promise (or discharge date) is the date promised when the patient was first scheduled in the MPS. We do not only measure lateness or tardiness but also earliness because we are interested in the accuracy of the predictions of the discharge. Tardiness as well as earliness contribute to a decreasing predictive performance. In fact we measure the mean absolute deviation between the original promised discharge date and the realised discharge date:[41]

$$\text{MADhisti} = \sum_{i=1}^{n} \frac{|DA_i - DO_i|}{n} \tag{4.2}$$

with DAi = the actual discharge date of patient i
DOi = the original discharge date of patient i
n = total number of patients flowing through the system

We will also compare the actual discharge date with the last updated planned discharge date (when updates occur)[42]. The measure is:

$$\text{MADcuri} = \sum_{i=1}^{n} \frac{|DA_i - DL_i|}{n} \tag{4.3}$$

with DAi = the actual discharge date of patient i
DLi = the last updated discharge date of patient i
n = total number of patients flowing through the system

In the following table we summarise the different criteria used to measure technical performance in this study.

[41] The MAD is again a very well known forecasting-error measure (Lee et al., 1987).
[42] Updates only occur when dynamic order due date maintenance is used.

Table 4.3. An overview of the different performance measures.

VARIABLE	DESCRIPTION
MPDi (MPDBED; MPDRX)	Mean absolute percentage deviation in actual resource requirements from estimated resource requirements. This will be collected for bed and Rx resources.
MADhisti	Mean absolute deviation between the actual discharge date and the original scheduled discharge date
MADcuri	Mean absolute deviation between the actual discharge date and the most recently updated scheduled discharge date

4.2.2. Planning performance measures

Because measuring planning performance is not part of the current study, we limit the discussion here to suggesting some measures which can be used in this case.

Three important planning performance measures must be considered: throughput time (i.e. the length of stay), capacity utilisation and workload fluctuation. Throughput times can be measured as the average length of stay of patients and capacity utilisation as the mean occupancy rate of the department. In measuring the occupancy rate, we suggest to use time-weighted statistics when the measuring points are not equally distributed over time. The literature proposes several criteria to evaluate the fluctuations in the utilisation and workload pattern. The workload standard deviation, the workload sequential deviation and the work load absolute deviation are well accepted measures comparing the current workload with respectively the average workload, the workload of the previous day and a standard workload (Shukla, 1985). Shukla further proposes to use a staffing stability index which is designed to assess the proportion of time that standard staffing patterns do not require adjustment.

4.2.3. Operating performance measures

The different sources of uncertainty in the hospital environment do not only influence the performance of HSRP, but also the operating performance of the hospital system itself. For instance the actual resource requirements change when one or more services are capacity-constrained. In a capacity-constrained environment, emergencies are more disturbing than in an environment with infinite capacity. A HSRP system must technically perform well in those hospital environments with the poorest operating performance. In other words, the technical performance of HSRP must be related with the operating performance of the hospital.

Measures of length of stay and occupancy are also an aspect of the operating performance of the hospital, but service level is another aspect of operating performance which may not be neglected.

Waiting times for patients are a common measure of service level (Lathrop et al., 1993). We are making a distinction between two types of waiting times: the waiting time before being admitted, i.e. the time between the first demand for admission and the actual admission, and the waiting time during the hospital stay.

The waiting time before admission is not always perceived as negative. Sometimes patients want to wait some time before surgery (if surgery is elective). We have observed in the University Hospitals that in a first step, the admission date is the result of an agreement between patient and physician. We call the result of this agreement the preferred admission date. In a second step, there is a check of the operating room capacity (if this capacity is finite). Based on this capacity check, the preferred admission date can be changed. This results in the actual admission date. The real waiting time is then the time between the preferred admission date and the actual admission date where the difference is caused by congestion in the hospital system. In our model the preferred admission date for scheduled patients is the date generated by a lognormal-distribution which describes the length of the period between first demand for admission and admission. When this period is changed because of for instance capacity limitations, this change will be registered as the number of days between the preferred admission date and the actual admission date. [43]

Due to the nature of health care delivery, queues generally do not form when a particular unit is fully utilised during the hospital stay (Cohen et al., 1980). As described earlier, blocking occurs. In this study, blocking means that a patient stays longer in the preoperative stage. Cohen et al. (1980) suggest to use the following measures:

(1) the fraction of transfers to the care units which are blocked;

(2) the proportion of the patient days which are due to inappropriate use caused by blocked transfers.

It must be remarked that blocking can lead to an increased length of stay and that those two performance measures are related.

[43] This performance measure is only different from zero when the capacity of some kind of resources is considered when scheduling admissions. This is not the case in the current study.

4.3. Hypothesis statement

In a previous section, we have identified two strategies to deal with uncertainty: (1) a strategy to reduce uncertainty and a strategy to buffer against uncertainty. The former strategy requires an increased capability to process information (Galbraith, 1973). This means that for instance more frequent replanning will be necessary or that additional features must be built into the HSRP (resulting in a more complex system). This increased information processing capability leads to higher costs. The increase in information processing capability will be higher the greater the uncertainty and the greater the task interdependence (Galbraith, 1973). Although cost of the system is not a performance measure in this study, it is important to note that the more the strategy to reduce uncertainty is used, the higher the cost of operationalising the HSRP system. This kind of strategy must substantially improve the performance of the HSRP system to be worthwhile. Furthermore, it is possible that the advantages of building in an additional feature to reduce a certain kind of uncertainty are off-set by the existence of other sources of uncertainty. The buffering strategy reduces the need for information processing (Galbraith, 1973). This means that the required level of performance of the HSRP may be lower. The main disadvantage of this kind of strategy is the reduced operating performance level because of the creation of slack resources or safety lead-time. One of the arguments to perform this study is that too much slack resources in hospitals can no longer be afforded because of cost-containment.
The task is to create a balanced HSRP system which allows to reduce uncertainty without a lot of slack resources and without creating too much information processing capabilities.

The following hypotheses state the expected relationship between a specific strategy to deal with uncertainty, sources of uncertainty and the technical performance of HSRP. The hypotheses are conceptual and not operational. The goal of the hypotheses is to have a framework to support our search of the more important dimensions in the development of HSRP.

In this basic experiment, we did not measure the planning performance of HSRP. After the exploration stage in this study, it must be determined whether it is worthwhile to further pursue more detailed questions (or hypotheses) (Emory, 1985, pp. 148). Planning performance will be tested in more specific follow-up experiments (which are not part of this study).

Hypothesis 1
The higher the uncertainty in the hospital environment, the lower the technical performance of the HSRP system.

Three factors contribute to higher uncertainty in the hospital environment: emergency, lead-time uncertainty and classification error. The more sources of uncertainty which are present in the environment, the lower the technical performance of HSRP. This hypothesis states that the presence of multiple sources of uncertainty has a cumulative negative impact on technical performance. The basis for this hypothesis of course is that each of the individual uncertainty factors significantly reduce the performance of the HSRP system.

Hypothesis 2
The higher the uncertainty in hospital demand and in the hospital process, the more frequent replanning is necessary to increase the technical performance of the HSRP system.

A higher replanning frequency allows the HSRP to be more responsive to changes in the MPS (Van Dierdonck, 1995) .This should lead to a better technical performance of the HSRP. Two kinds of changes are possible: changes in the actual demand during the freezing interval and changes in the discharge date (due date) of released orders (patients in stage). The first change occurs in the case of emergencies or scheduled patients for whom the time between scheduling and discharge is lower than the replanning periodicity (freezing interval). The second change occurs when the actual lead time of patients in some stage is different from the planned lead time. This can be the result of lead-time variation and/or classification error. The second change implies a dynamic order due date strategy to adapt the MPS to such changes. This kind of MPS changes are crucial taking into account that lead time variability has a significant influence on the technical performance (Cheng, 1987).

An increased planning frequency is required when uncertainty increases (Galbraith, 1973) but at the same time frequent replanning seems to be undesirable (Lin et al., 1992 referring to several other authors; Zhao et al., 1993) because of system nervousness. This means that if a higher planning frequency does not lead to significant improvements in technical performance, it is desirable to use the lower frequency.

Hypothesis 3

By reducing the amount of process uncertainty, a dynamic order due date maintenance strategy increases the technical performance of HSRP. In particular this strategy has a significantly positive effect on the accuracy of the prediction of the discharge date. This increase in performance will be higher when the replanning frequency is higher.

Because a dynamic order due date maintenance procedure compares the actual and the planned pre-operative length of stay, the lead-time uncertainty in this stage can be reduced. The reduction of lead-time uncertainty should have a significant impact on the technical performance of the HSRP system (see Huang et al., 1985; Cheng, 1987).

Dynamic order due date maintenance gives more up-to-date information about the status of the order. The faster the MPS can adapt to this new information, the better the performance of the HSRP (see hypothesis 1).

Dynamic order due date maintenance means that the discharge date in the MPS is rescheduled based on the updated information. This rescheduling leads to a new discharge date which should better approach the actual discharge date.

Hypothesis 4

In the case of uncertain lead times, a safety lead time buffer strategy improves the technical performance of HSRP in any of the configurations. A safety lead time strategy is even better than holding safety capacity.

Uncertain lead times create timing uncertainty and in the case of timing uncertainty, safety lead time seems to be a better strategy than holding safety capacity. This is based on the research of Whybark et al.(1976) when we assume that safety capacity can be considered as a kind of safety stock in the case of service delivery. This finding is partially supported by the findings of Buzacott et al.(1994) that in a single stage production environment with no forecast errors, safety lead time can be preferred to safety stock. Although the hospital environment in this study is a multistage environment, forecast errors are not present.

Hypothesis 5
The technical performance of HSRP is significantly worse in the case of limited capacity (moderate slack) than when there is infinite capacity (a lot of slack) unless there is a strategy of frequent replanning with dynamic order due date maintenance.

When capacity limits are introduced, blocking (and misplacement) will occur. In this study, blocking means that patients are inhibited to go to the surgery room and are kept longer in a pre-operative department. This will lead to an increased length of stay. Dynamic order due date maintenance allows to change the discharge date of patients when they are blocked. Frequent replanning enhances the opportunities to adapt the discharge date to the most current information (see hypothesis 2).

Hypothesis 6
Even with a lot of safety capacity, it can be worthwhile to reduce uncertainty by installing a planning (information) system.

When there is infinite capacity, safety capacity reduces the number of blockings (Cohen et al., 1980), allows to treat emergencies (Dowling, 1976) and is a buffer against the timing uncertainty introduced by lead-time uncertainty in the different treatment stages (see Schmitt, 1984). Nonetheless some of the strategies to reduce uncertainty can still add some value in terms of technical performance and service level. For instance, dynamic order due date maintenance allows to change the due date in the MPS based on the difference between the planned and the actual preoperative length-of-stay. This should improve the technical performance. In other words, a buffer strategy of safety capacity cannot deal with all sources of uncertainty.

Hypothesis 7
The introduction of the classification error strongly reduces the technical performance of the HSRP system in all configurations. This reduction in performance increases when the differences between the DRG categories increase.

A wrong classification means that the wrong MPS is used, that the wrong planned lead times and the wrong resource utilisation standard units are used. The amount of reduction of the performance will depend on the degree to which the bill of resources for the end-items (MPS) are different. When the differences are limited, it is possible that resource commonality alleviates the uncertainty introduced by the classification error (Collier, 1981; Ho et al., 1993).

Hypothesis 8
In the case of high process uncertainty, the technical performance will be significantly better for resources which are completely length of stay dependent (beds) than for resources which are only partially length of stay dependent (chest X-ray).

This hypothesis is based on the fact that a greater uncertainty means that there are more patients with a longer length of stay on a certain department (because of the skewed distributions to the right). For resources which are not length of stay dependent in a certain department, the same number of procedures is divided over a longer length of stay. In contrast, the HSRP system works with an average daily figure. The difference between the actual number of procedures performed on a certain day (a multiple of one) and the planned number of procedures performed on the same day (a multiple of one divided by the length of stay) increases with a longer length of stay.
Another explanation which supports this hypothesis is that when resources are length of stay dependent there is only one source of uncertainty: the length of stay (or lead time). In the case of independence, there are two sources of uncertainty: the lead time and the number of procedures consumed during the length of stay.

4.4. A simulation-based experimental investigation

In a previous paragraph, we have identified 7 factors. We measure each of these factors on two levels. This means that there are 2^7 or 128 combinations . We call these combinations 'treatments'. In simulation, experimental design provides a way of deciding before the runs are made which particular treatments to simulate so that the desired information can be obtained with the least amount of simulating (Law et al., 1992, p.657).

Generally, there are three different approaches to the design of experiments (Kleijnen, 1987, p.260):

1. One factor at a time approach
2. Full factorial design
3. Incomplete factorial design.

The first approach does not allow to estimate interaction effects (Box et al., 1978). In this study estimation of the interaction effects is necessary to give an answer on the hypothesis statements. Understanding the pattern of interaction of the factors is often the key to finding the combination that gives the best system performance (Thesen et al., 1992). The problem with full factorial designs is that in the case of many factors, the number of combinations becomes impractical (Kleijnen, 1987, p.260).

Although, the incomplete factorial design allows to investigate many factors in a relatively small experiment, there is the problem of confounding. Confounding means that in such design one may end up with exactly the same algebraic expression for different effects (Law et al., 1992, p.671). For instance when two two-way interaction effects are confounded with each other, this means that formulas for these effects are identical, and that their effects are confused. In order to assure that no confounding occurs for main effects and first order interaction effects, one needs a resolution V design.[44]

In order to choose a practically feasible design, one must be aware that each configuration must be replicated several times to make valid estimates (Kleijnen, 1987, p.290). In an exploratory stage of the simulation investigation, Kleijnen (1987) proposes to limit the number of replications to a small number (between 2 and 5). If we choose (for example) 5 replications, we need 640 simulation runs in the case of a full factorial design. We have also observed that almost all applications in simulation use a full factorial design (see also Kleijnen, 1987, p.292). With the increasing speed of the current computers, 640 simulation runs do not seem impractical.[45]

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[44] A design of resolution R is one in which no p-factor effect is confounded with any other effect containing less than R-p factors. For instance a design with R = III does not confound main effects with one another, but does confound main effects with two-factor interactions (Box et al., 1878, p.385).

[45] The duration of 5 runs is in average 30 minutes. To perform 640 simulation runs, we need 64 hours of computer simulation (IBM compatible PC, pentium, 90 mhz).

When a full factorial design approach is chosen in which factors have two levels, a design matrix can be constructed where the first level of each factor is represented by a "-" and the second level of each factor is represented by a "+". Table 4.4. shows the design matrix for this study (Box et al., 1978). In the same table the "+" and "-" levels are defined for each factor. With each treatment corresponds a response R_i.

The design matrix allows to determine in a very easy way the main and interaction effects [46]. If there are k factors, then the main effects measure the average change in the response due to a change in an individual factor, with this average being taken over all possible combinations of the other k-1 factors. To compute the main effects e_j we apply the signs in the "factor j" column to the corresponding responses R_i's, add them up and divide by 2^{k-1}. It is possible that the effect of factor j_1 depends in some way on the level of some other factor j_2. This means that there is a two-factor (or two-way) interaction effect. In this case we multiply the *i*th sign in the factor j_1 column with the *i*th sign in the factor j_2 column and we apply this sign to the response R_i. We repeat this procedure for each *i*th row in the design matrix. Then we add up all R_i's and divide by 2^{k-1}. In the same way, three- and higher factor interaction effects can be computed. The problem with these higher interaction effects is that their interpretation becomes more difficult.

The core question of course is whether these main and interaction effects are significant or not. We will deal with this question in the next part on the analysis of the simulation output.

[46] This paragraph is based on Law et al., 1992, pp.661-662.

Table 4.4. Design matrix for this study

Treatment	Due date maintenance (-) no (+) yes	Cap limits (-) no (+) yes	lead-time uncertainty (-) low (+) high	Safety lead-time (-) no (+) yes	emergencies (-) no (+) yes	Classification error (-) no (+) yes	Frequency (-) low (+) high
1	-	-	-	-	-	-	-
2	+	-	-	-	-	-	-
3	-	+	-	-	-	-	-
4	+	+	-	-	-	-	-
5	-	-	+	-	-	-	-
6	+	-	+	-	-	-	-
7	-	+	+	-	-	-	-
8	+	+	+	-	-	-	-
9	-	-	-	+	-	-	-
10	+	-	-	+	-	-	-
11	-	+	-	+	-	-	-
12	+	+	-	+	-	-	-
13	-	-	+	+	-	-	-
14	+	-	+	+	-	-	-
15	-	+	+	+	-	-	-
16	+	+	+	+	-	-	-
17	-	-	-	-	+	-	-
18	+	-	-	-	+	-	-
19	-	+	-	-	+	-	-
20	+	+	-	-	+	-	-
21	-	-	+	-	+	-	-
22	+	-	+	-	+	-	-
23	-	+	+	-	+	-	-
24	+	+	+	-	+	-	-
25	-	-	-	+	+	-	-
26	+	-	-	+	+	-	-
27	-	+	-	+	+	-	-
28	+	+	-	+	+	-	-
29	-	-	+	+	+	-	-
30	+	-	+	+	+	-	-
31	-	+	+	+	+	-	-
32	+	+	+	+	+	-	-
33	-	-	-	-	-	+	-
34	+	-	-	-	-	+	-
35	-	+	-	-	-	+	-
36	+	+	-	-	-	+	-
37	-	-	+	-	-	+	-
38	+	-	+	-	-	+	-
39	-	+	+	-	-	+	-
40	+	+	+	-	-	+	-
41	-	-	-	+	-	+	-
42	+	-	-	+	-	+	-
43	-	+	-	+	-	+	-
44	+	+	-	+	-	+	-
45	-	-	+	+	-	+	-
46	+	-	+	+	-	+	-
47	-	+	+	+	-	+	-
48	+	+	+	+	-	+	-
49	-	-	-	-	+	+	-
50	+	-	-	-	+	+	-
51	-	+	-	-	+	+	-
52	+	+	-	-	+	+	-
53	-	-	+	-	+	+	-
54	+	-	+	-	+	+	-
55	-	+	+	-	+	+	-
56	+	+	+	-	+	+	-
57	-	-	-	+	+	+	-
58	+	-	-	+	+	+	-
59	-	+	-	+	+	+	-
60	+	+	-	+	+	+	-
61	-	-	+	+	+	+	-
62	+	-	+	+	+	+	-
63	-	+	+	+	+	+	-
64	+	+	+	+	+	+	-

65	-	-	-	-	-	-	+
66	+	-	-	-	-	-	+
67	-	+	-	-	-	-	+
68	+	+	-	-	-	-	+
69	-	-	+	-	-	-	+
70	+	-	+	-	-	-	+
71	-	+	+	-	-	-	+
72	+	+	+	-	-	-	+
73	-	-	-	+	-	-	+
74	+	-	-	+	-	-	+
75	-	+	-	+	-	-	+
76	+	+	-	+	-	-	+
77	-	-	+	+	-	-	+
78	+	-	+	+	-	-	+
79	-	+	+	+	-	-	+
80	+	+	+	+	-	-	+
81	-	-	-	-	+	-	+
82	+	-	-	-	+	-	+
83	-	+	-	-	+	-	+
84	+	+	-	-	+	-	+
85	-	-	+	-	+	-	+
86	+	-	+	-	+	-	+
87	-	+	+	-	+	-	+
88	+	+	+	-	+	-	+
89	-	-	-	+	+	-	+
90	+	-	-	+	+	-	+
91	-	+	-	+	+	-	+
92	+	+	-	+	+	-	+
93	-	-	+	+	+	-	+
94	+	-	+	+	+	-	+
95	-	+	+	+	+	-	+
96	+	+	+	+	+	-	+
97	-	-	-	-	-	+	+
98	+	-	-	-	-	+	+
99	-	+	-	-	-	+	+
100	+	+	-	-	-	+	+
101	-	-	+	-	-	+	+
102	+	-	+	-	-	+	+
103	-	+	+	-	-	+	+
104	+	+	+	-	-	+	+
105	-	-	-	+	-	+	+
106	+	-	-	+	-	+	+
107	-	+	-	+	-	+	+
108	+	+	-	+	-	+	+
109	-	-	+	+	-	+	+
110	+	-	+	+	-	+	+
111	-	+	+	+	-	+	+
112	+	+	+	+	-	+	+
113	-	-	-	-	+	+	+
114	+	-	-	-	+	+	+
115	-	+	-	-	+	+	+
116	+	+	-	-	+	+	+
117	-	-	+	-	+	+	+
118	+	-	+	-	+	+	+
119	-	+	+	-	+	+	+
120	+	+	+	-	+	+	+
121	-	-	-	+	+	+	+
122	+	-	-	+	+	+	+
123	-	+	-	+	+	+	+
124	+	+	-	+	+	+	+
125	-	-	+	+	+	+	+
126	+	-	+	+	+	+	+
127	-	+	+	+	+	+	+
128	+	+	+	+	+	+	+

4.5. Simulation modelling

4.5.1. The modelling approach: simulation

The research method used in this study can be described as an experimental investigation of the performance of the HSRP system under different kind of uncertainties which are observed in a hospital environment. Because the HSRP system is in no way an operational planning system, we cannot set up an experimental design or quasi-design (Emory, 1980) through the implementation of the HSRP system in an actual operating environment.[47] When experimentation with the actual system is not possible, we have to experiment with a model of the system (figure 4.1.).

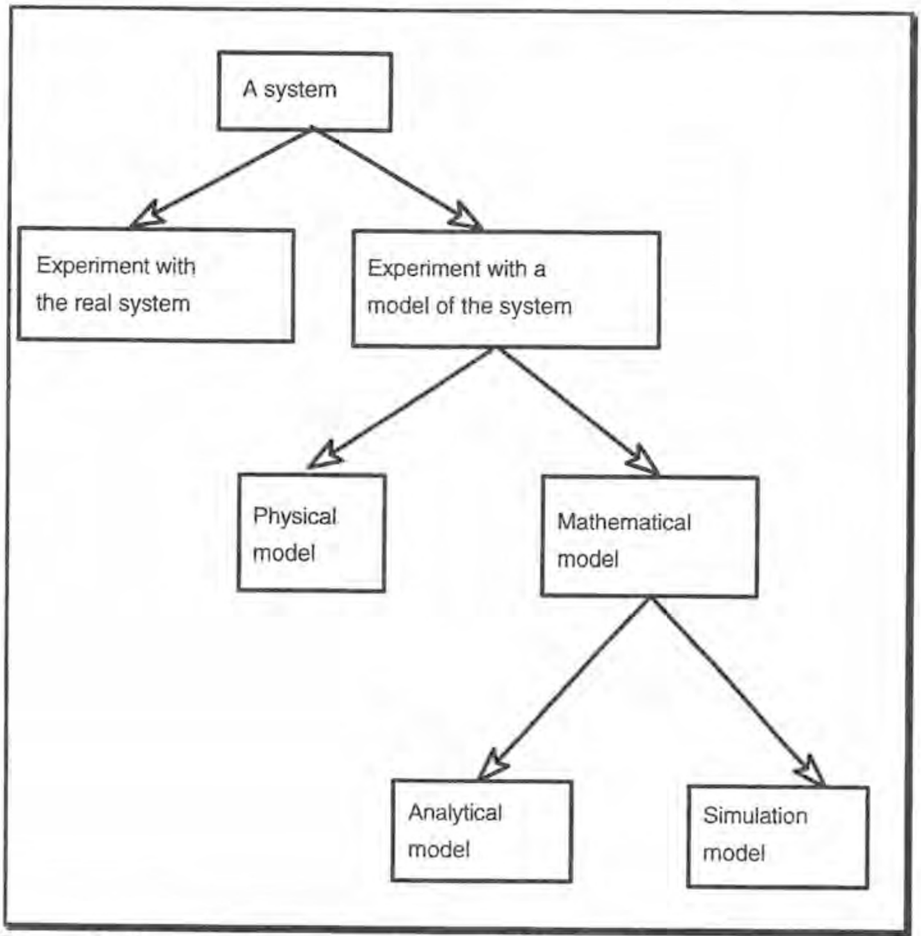

Figure 4.1. Ways to study a system (Law et al., 1991, p.4)

The common modelling approach used in studying the behaviour of a (manufacturing) planning system under different sources of uncertainty or in a specific environment is simulation. This can be observed in many of the MRP/MPS studies (e.g. Whybark et al., 1976; Grasso et al., 1984; Schmitt, 1984; Sridharan et al.; 1990, Ho et al., 1993; Brennan et al., 1993). In the hospital management science literature, there are many examples of the use of simulation to evaluate the

[47] An example of such an experimental design approach for the evaluation of s surgical scheduling system can be found in Lowery (1989).

performance of scheduling rules or scheduling systems in a hospital environment (Fetter et al., 1965; Robinson et al., 1968; Goldman et al., 1968; Hearn et al., 1970; Kwak et al., 1976, Cohen et al., 1980; Harris, 1985; Dumas, 1984 & 1985).

Notwithstanding the extensive use of simulation in this kind of research, there are also examples of studies which use analytical models. Examples of the application of a mathematical model to the problem of MPS performance under uncertainty can be found in Lin et al (1992) , Lin et al. (1994) and Buzacott et al. (1994). In the hospital literature, we have found the example of semi-Markov process models which have been used in studying the effect of capacity constraints in care units on some performance measures (Kao, 1974; Hershey et al., 1981).

The choice between a simulation model and an analytical model is generally based on (1) the availability of an analytical model for the problem and (2) the extent to which the analytical model fits the conditions of the problem (Schriber, 1991). If there is no fit or the fit can only be obtained by introducing too many restrictive assumptions, the resulting model may not produce a solution for the original problem. The limits of analytical models are rapidly emerging when increasing realism is introduced in the system. For instance in the case of semi-Markov process models, it is suggested to use simulation when more than one nursing unit has finite capacity (Hershey et al., 1981).

The specificity of our research problem in combination with the complexity of the system to be modelled (see further) prohibits the use of an analytical model in this study. Furthermore, our aim to model the hospital environment as realistic as possible is in contrast with the abstraction requirements in analytical models.

We have identified two different approaches in the MRP/MPS simulation studies. A first approach is to model the MPS/MRP system without modelling the shop floor. Uncertainty is introduced by manipulating the design factors of the MRP/MPS system. This approach can be found in all of the above mentioned simulation studies about MRP/MPS performance in uncertain environments. A second approach integrates the MRP-based control level and the shop-level. In this case, the shop level is also modelled. An example of this approach can be found in Huang et al. (1985). This approach allows to evaluate a MRP system within the context of a realistic shop scenario (Huang et al., 1985). Because the specificity of the hospital operating environment is very important in this study, we believe that the second approach can be preferred above the first one.

4.5.2. The logic behind the simulation model

The core assumption of our simulation model is that the flow of patients through the network of service units is ´folded´ in a compact form through the use of a transition-probability matrix. Kao (1974) indicates that "this simplification will be particularly beneficial when simulation or analytical techniques are applied to study the related planning and control problems that encompass the aggregation of patients with different diagnosis" (Kao, 1974). The following table 4.5. shows the transition probability matrix used in this study. For instance 69% of the patients in department 2191D (1) have as destination department 8140C (2), 24% have as destination department 8325D (3) and 7% have as destination department 8327C (4). The percentages in the table are based on the absolute number of transfers that we have observed in our case hospital[48].

Table 4.5. The transition probability matrix used in this study.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**11**	**12**	**20**
1	-	69*	24	7	-	-	-	-	-	-	-	-
2	0	-	0	100	-	-	-	-	-	-	-	-
3	38	5	-	57	-	-	-	-	-	-	-	-
4	-	-	-	-	0	88	10	-	-	-	-	2
5	-	-	-	-	-	33	-	33	-	-	-	33
6	-	-	-	-	0	-	1	4	-	-	-	95
7	-	-	-	-	5	78	-	5	-	-	-	12
8	-	-	-	-	-	-	-	-	88	-	-	12
9	-	-	-	-	-	-	-	-	-	20		80
11	-	-	-	-	-	-	-	-	-	-	67	33
12	-	-	-	-	-	-	-	-	-	-	-	100

* in percentages
1 = 2191D = Cardiology, preoperative
2 = 8140C = Heart Surgery, medical, preoperative
3 = 8325D = Intensive Care, general, preoperative
4 = 8327C = Intensive Care, heart surgery, preoperative
5 = 2191DO = Cardiology, postoperative
6 = 8140CO = Heart Surgery, medical, postoperative
7 = 8325DO = Intensive Care, general, postoperative
8 = 8327C2 = Intensive Care, heart surgery, postoperative, second attendance
9 = 8140CO2 = Heart Surgery, medical, postoperative, second attendance
11= 8327C3 = Intensive Care, heart surgery, postoperative, third attendance
12 = 8140C3 = Heart Surgery, medical, postoperative, third attendance.
20 = Leaving the hospital

The system which is simulated has two levels (see figure 4.2.). The first (shop) level shows the actual flow of patients through a network of four different units with infinite or finite capacity. A similar approach has been used by Davies (1994) in a simulation for planning services for patients with coronary artery disease.

The second (planning) level simulates a HSRP system. In the base experiments, there is no interaction between the two levels because the HSRP is not (yet) used as a decision support tool.

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[48],See table 3.1."The absolute number of transition in the case study"in section 3.3. Sources of uncertainty in the hospital.

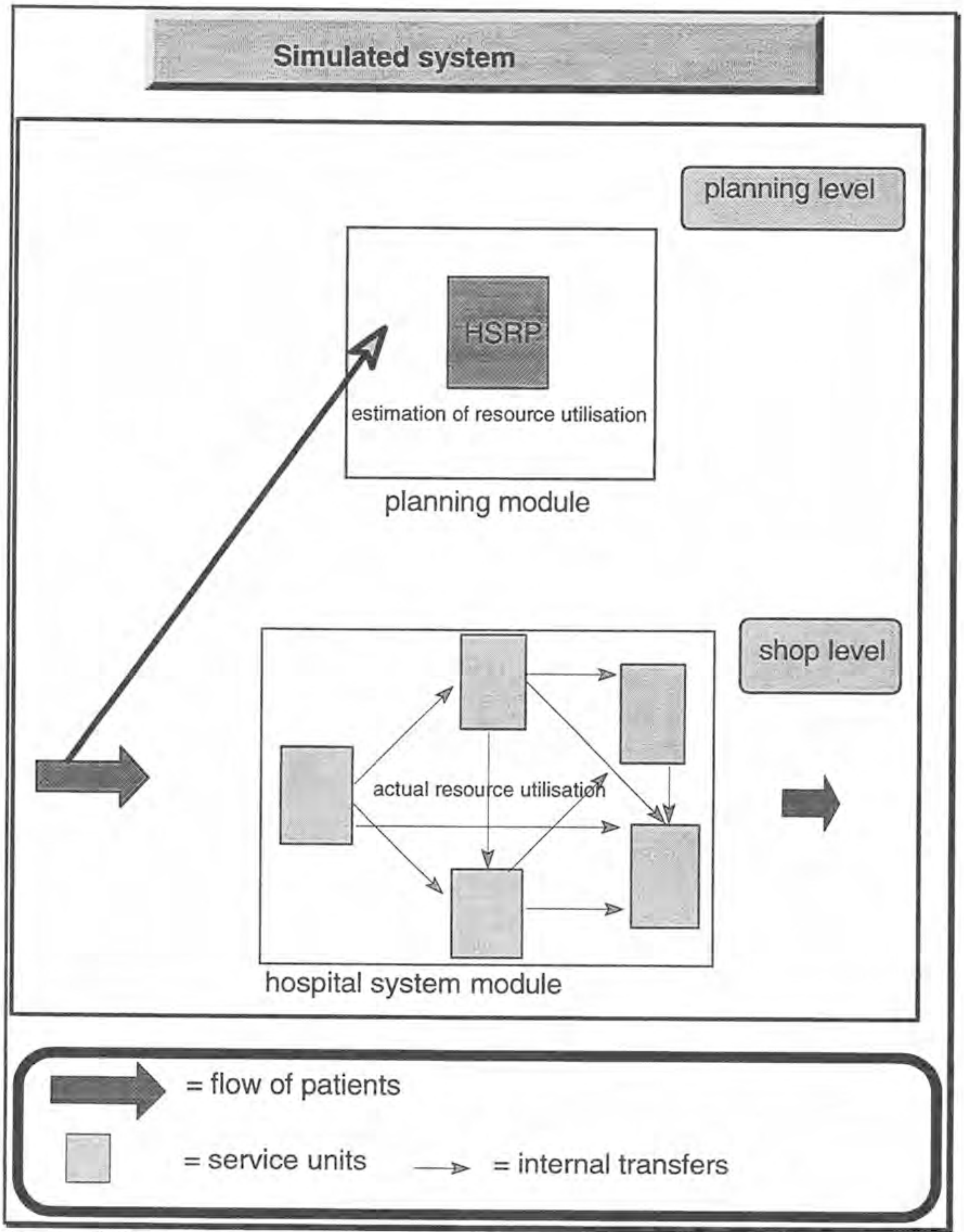

Figure 4.2. The simulated system: shop and planning level.

Each 24 hours, a number of patients are generated according to a Poisson distribution [49]. This generation reflects the demand of patients for a surgical care admission. Different attributes are assigned to the patients (e.g. emergency admission or not, kind of DRG). Based on these characteristics and on the transition probability matrix, the patient flows through a network of four departments (table 4.6.). Only one of these departments (8327C) is modelled with finite capacity. When flowing through this network, stage-specific daily statistics on actual resource

[49] The choice of a Poisson distribution is explained in a later section.

utilisation are collected. Three stages are defined: preoperative, surgical and postoperative stage. The consumption of length of stay independent resources are (equally) spread over the time period that a patient stays in a specific department.

Table 4.6. Departments modelled in the hospital system.

NUMBER	DEPARTMENT
2191D	Cardiology
8140C	Heart surgery, medical department
8327C	Heart surgery, intensive care
8325D	Intensive care unit

At the moment of demand, the discharge date of the patient is scheduled in the Master Production Schedule. The kind of DRG determines which MPS is used. The discharge date is the result of a calculation on the scheduled admission date using a predetermined average length of stay. The admission date depends on the emergency status of the patient and on a distribution which models the preferred time between demand and admission for scheduled patients. Periodically an explosion of the Master Production Schedule is performed to calculate the number of patients in the different (preoperative, surgical and postoperative) stages. These calculations are based on statistics (averages) collected in previous periods. This means that (besides the normal warm-up period[50]) the model must run for some time without HSRP explosion to collect statistics which can be used in the HSRP explosion. Estimated resource utilisation for different kinds of resources is calculated based on the number of patients in each stage on each day.
At the time that the patient enters for the first time the surgical stage, there is a possibility to compare the actual lead time (until that moment) with the planned lead time (until that moment) for each patient. This comparison can lead to a change in the MPS.
The estimated and actual figures on resource utilisation are compared and this allows to calculate the technical performance.

4.5.3. The structure of the simulation program

The structure of the simulation program is shown in figure 4.3.. The different modules are shortly discussed. The simulation program and a more detailed documentation can be found in appendix 8. Here we shortly discuss the most important modules.

[50] The concept of warmup period will be explained later.

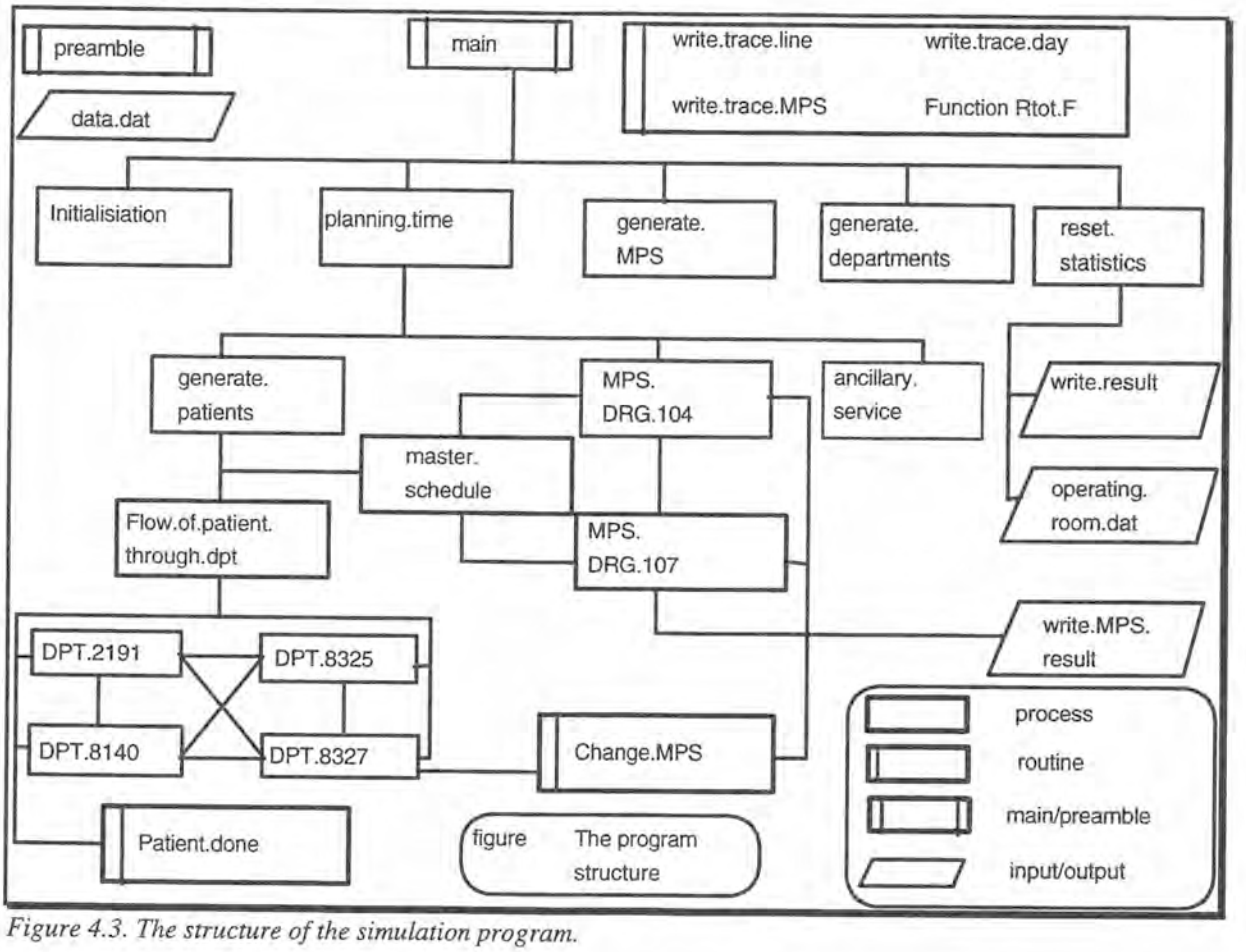

Figure 4.3. The structure of the simulation program.

Main.

This module is the heart of the model. It calls the initialisation module, activates the modules which generate the MPS and the resources such as departments. It also calls the planning time process and the reset statistics module. It starts simulation and closes the output units.

Initialise

In the initialisation routine, the input parameters in the data.dat file are read. In this routine the different destinations of the output reports and trace-files are opened. The tracefiles are created in function of validation.

Data.dat

Data.dat is an input form where the different parameters, distributions and random variables can be specified. Table 4.7. shows this input form.

Table 4.7. The input form DATA.DAT [51]

```
'Experimental parameters
7            Planning periodicity
0 0 1 1 *    Emergencies
0 0 1 1 *    Classification error
1            Dynamic order due maintenance (0= No; 1 = Yes)
1            Capacity limits (0= No; 1= Yes)
0            Admission scheduling strategy (0= No)
1.25         Lead-time uncertainty (1= low; 1.25 = high)
0.25         Safety lead time (0= No; 0.25 = Yes)
1500         Run length
 400         Warm-up period
 200         Reset time (Interval to collect standardised time units)
 200         After this time statistics are collected in the reset interval/ warm-up HSRP (a)
 140         Reset Interval
  35         Planning.horizon
   4         Number of Departments
   5         Maximum Number of beds on Intensive Care (ICU.BEDS)
   1         Use of the lognormal distr (1=Y; 0=N)( P5)
1.0 1.0 *    The service intensity of chest X-ray per 24 hrs

"Transition probability matrix
0.31 1 0.86 2 0.99 3 1.00 4         *
0.69 2 0.935 3 1.00 4               *
0.003 3 1 4                         *
0.38 1 0.43 2 1 4                   *
0.88 6 0.98 7 1 20                  *
0.33 6 0.66 8 1 20                  *
0.003 5 0.013 7 0.053 8 1 20        *
0.05 5 0.84 6 0.89 8 1 20           *
0.88 9 1 20                         *
0.2 11 1 20                         *
0.67 12 1 20                        *
1 20                                *

" Length of stay distributions in each matrix cell
0.0 0 0.031 19 0.229 51 0.375 84 0.500 117 0.656 149 0.739 182 0.865 215
0.906 247 0.917 280 0.937 313 0.948 345 0.958 411 0.969 476 0.979 476
0.989 508 1 639                                  * LOS matrix cell 5
0.00 0 0.176 8 0.294 20 0.765 33 0.794 46 0.823 60 0.853 85 0.912 125
0.941 190 0.971 229 1 255*                       * LOS matrix cell 6
0.00 0 0.33 19 0.66 27 1 161                     * LOS matrix cell 7
0.00 0 1 20                                      * LOS matrix cell 9
0.00 0 0.007 11 0.023 21 0.088 31 0.108 41 0.711 51 0.750 61 0.816 71
0.931 81 0.937 91 0.967 101 0.974 111 0.980 121 0.987 131 0.997 151
1 741                                            * LOS matrix cell 10
0.00 0 0.031 8 0.125 21 0.406 35 0.656 48 0.719 61 0.844 75 0.969 102
1 264                                            * LOS matrix cell 11
0.00 0 0.33 23 0.66 44 1 106                     * LOS matrix cell 12
0.00 0 0.125 12 0.479 35 0.583 58 0.729 80 0.812 103 0.896 125
0.938 148 0.979 194 1 216                        * LOS matrix cell 13
0.0 0 0.041 23 0.188 33 0.241 43 0.680 53 0.708 63 0.836 73 0.912 83
```

[51]. (*) in the data.dat form indicates those variables which are defined through a random step or random linear variable.For instance '0 0 1 1 *' in the case emergencies means that 0% of the patients are emergency (0) and 100% are non-emergency. '0.5 0 0.5 1' means that there is a 50% chance that the next patient has the status 'emergency'.

```
0.921 93 0.949 103 0.953 113 0.962 123 0.966 143 0.978 153 0.981 173
0.984 203 0.987 243 0.990 253 0.994 263
0.997 463 1 803                                     * LOS matrix cell 15
0.0 0 0.368 24 0.763 50 0.842 76 0.895 102 0.921 180 0.947 233 0.974 389
1 520                                               * LOS matrix cell 16
0.0 0 0.33 1 0.66 25 1 279                          * LOS matrix cell 17
0.00 0 1 7                                          * LOS matrix cell 21
0.00 0 1 7                                          * LOS matrix cell 23
0.00 0 1 73                                         * LOS matrix cell 25
0.00 0 1 291                                        * LOS matrix cell 28
0.00 0 0.33 25 0.66 126 1 528                       * LOS matrix cell 29
0.00 0 0.33 1 0.66 40 1 355                         * LOS matrix cell 30
0.00 0 0.018 127 0.096 157 0.415 187 0.701 217 0.815 247 0.883 307
0.907 337 0.937 367 0.949 396 0.958 426 0.970 486 0.982 545
0.985 605 0.988 963 0.991 1083 0.994 1112 0.997
1142 1 1291                                         * LOS matrix cell 31
0.00 0 1 27                                         * LOS matrix cell 35
0.00 0 0.182 21 0.757 42 0.848 63 0.909 84 0.939 146 0.969 209
1 418                                               * LOS matrix cell 36
0.00 0 0.50 14 1 140                                * LOS matrix cell 37
0.00 0 0.33 46 0.66 154 1 1112                      * LOS matrix cell 38
0.0 0 0.33 5 0.66 39 1 239                          * LOS matrix cell 42
0.0 0 1 12                                          * LOS matrix cell 44
0.0 0 0.33 60 0.66 178 1 463                        * LOS matrix cell 49
0.0 0 0.33 44 0.66 218 1 650                        * LOS matrix cell 50
0.0 0 1 19                                          * LOS matrix cell 60
0.0 0 1 10                                          * LOS matrix cell 62
0.0 0 0.50 45 1 437                                 * LOS matrix cell 68

" RX distributions for those departments where it is not length of stay dependent
.24 0 .82 1 .97 2 .99 3 1.0 4                       * Department 2191
.14 0 .96 1 .99 2 1.0 4                             * Department 8140.preoperative
.02 0 .04 1 .11 2 .64 3 .91 4 .96 5 .98 6 1.0 9     * Department 8140 postoperative
```

Process Planning.Time

This is an event driven timing module. The event is 24 hours which pass. Each 24 hours a number of requests for admission is generated. The further specification of the patients is performed in another module 'GENERATE PATIENTS'. The module PLANNING TIME activates the module ANCILLARY SERVICE calculating the planned and actual resource requirements. This module also calls the MPS.DRG.104 routine which is the first routine in the MRP explosion process. An input parameter specifies the planning interval, i.e. the interval between two consecutive calls of the MPS.DRG.104 routine.

Process Ancillary.Service

One of the functions of this process is to track the daily occupancy of the different departments in order to calculate the daily consumption of resources which are length of stay dependent. This module also collects daily statistics on the actual and planned resource consumption (for beds and chest X-rays) across the different MPS schedules.

Process Generate.Patients

In this module, patients are further specified. Different attributes such as patient identification and the department where the patient will be admitted are assigned. Based on a random step input parameter, it is determined whether a patient is an emergency or not. In the case of emergency, a patient will be immediately admitted. In the case of non-emergency, the admission date is scheduled using a theoretical distribution.

If the patient starts at the 2191 department (cardiology), he/she receives a flag 1 (path attribute). Patients with a 'path = 1' attribute are classified in DRG 104. The other patients are DRG 107 patients. At this point, it is possible to introduce a classification error.

This module activates a process called FLOW.OF.PATIENT.THROUGH DPT. This process starts the actual flow of patients through the hospital departments dependent on the admission date.

After the warm-up period and after some reset time, the process Master Schedule is activated.

Process Master.Schedule

In this process, generated patients are scheduled in the DRG specific MPS. Dependent on the number of the DRG category, a MPS is chosen. Based on the planned admission date of a patient and a DRG specific average length of stay, the discharge date of the patient is calculated. This day is then sought in the MPS and the gross requirements on this day is increased with one.

Process Flow.Of.Patient.Through.Dpt

In this process, patients are admitted on the right admission date and sent to the appropriate admission department. Each day, the process is activated.

Patients are kept waiting until their scheduled admission date is met. Once the current date is the admission date, patients are placed in a queue before a department. This is not a real queue, but it is a set which is necessary to create a link between this module and the different department specific modules. The process of the identified admitting department is then activated.

The flow of patients through the different departments is completely based on a transition probability matrix. Using linear random variables a patient in a certain department receives a destination (i.e. a department or the status of leaving the hospital). This destination is not influenced by the previous sequence of departments which the patient has visited. The length of stay in the current department depends on the nature of the current department and of the destination.

Process DPT.2192/ Process DPT.8325 / Process DPT.8140/ Process DPT.8327

These processes model the different departments. The primary function is to assign a length of stay to each patient taking into account the current department and the destination department and based on some kind of length of stay distribution. The processes are completely managed by the underlying transition probability matrix and the associated length of stay distributions (see also the input form in table 4.7.). The length of stay of patients on departments with a high volume of coronary care patients is modelled with a theoretical distribution . The length of stay distributions are department and stage specific. The theoretical distributions have a parameterised standard deviation. This allows to change the amount of lead time uncertainty.

The second function of these processes is to register the actual resource consumption for those resources which are not length of stay dependent (e.g. chest X-ray in some of the departments). Using a random step variable, the actual amount of resources consumed by a particular patient is collected.

When the stay of the patient on a department is finished, the patient leaves the department and is put in the queue of the destination department or in the patient done queue. The processes related with this destination department or with the patient done queue are then activated. For patients with the intensive care unit as destination, a special procedure is built in to account for the finite capacity of the Intensive Care Unit (8327C). When a finite capacity strategy is chosen, the patient is blocked when the bed capacity of the ICU is full. Blocking means that the patient is kept one day longer on the ICU than necessary. This procedure is repeated until there is free bed capacity on the ICU unit.

In the process module of the ICU (8327C), a feature is developed to create a link between the actual flow of the patients and the MPS. For each patient it is calculated how many days earlier or later than scheduled the patient arrives at the intensive care unit. This is based on a comparison of the actual preoperative length of stay and the planned (or average) preoperative length of stay. If the difference between actual and planned figures is equal to or greater than one day, a process called 'CHANGE.MPS' is activated in order to change the scheduled discharge date in the MPS.

Routine Patient.Done

In this routine, the finished patients are discharged from the hospital and statistics (total, DRG specific, stage specific) are collected.

Process Generate.MPS

In this process, the MPS is developed for a certain number of periods (days). The number of periods is at least greater than the planning horizon. After some time of simulation, a number of periods is added to the MPS and past periods are deleted. The number of periods is large enough to allow smooth working of MPS scheduling and MRP explosion.

Process Generate.Departments

In this module, departments are modelled as resources with some bed capacity. The capacity levels are set in such a way that it reflects infinite capacity for the four departments with the possibility of limiting the capacity. Modelling departments as resources give some helpful modelling features.

Process Reset.Statistics

This process allows to divide the total simulation time in batches in order to produce statistics over different iterations. After each iteration, a summary of the results is printed in the routine WRITE.RESULT.

Routine MPS.DRG.104/ Routine MPS.DRG.107

This routine contains the MRP explosion for respectively DRG 104 patients and DRG 107 patients.

These routines start with identifying the date of the current day. Using the planning horizon parameter, it is determined what the last day is for the current offsetting. For each day of the planning horizon, the changes in the number of patients to be discharged on this day are calculated.

For each day of the planning horizon and based on the gross requirements on each day, offsetting is performed. Offsetting means that starting from the discharge date, the patient is assigned to a number of days postoperative care. This number is based on statistics collected. Once it is known when the patient must arrive in the postoperative stage, the same procedure can be followed for the surgical stage and the preoperative stage. It is assured that the calculations are performed only for patients who have not been scheduled on the MPS during the previous planning period (net change).[52]

Some data for determining resource requirements are collected. The total number of patients in preoperative, postoperative and the surgical stage on the days of the current planning period is used to calculate the planned resource consumption.

---

[52] If the discharge of a new patient is scheduled on day x and a patient with discharge date on the same day is rescheduled, the net change is zero. Because the MPS is DRG specific, all patients with a discharge date on the same MPS, have the same standard lead times.

Routine Change.MPS

This routine changes the discharge (due date) of a patient in the MPS based on information which is collected on the shop floor (just after the preoperative stage and just before entering the intensive care unit). Dependent on the kind of DRG, the current discharge date of the patient on the MPS is sought. If this date is found, the number of discharges on this date is subtracted with one. In the following step, the new discharge date is sought in the MPS. This new discharge date is based on the comparison of the actual preoperative length of stay and the planned preoperative length of stay, a calculation which is performed in the process DPT.8327. When the new discharge date has been found, the number of discharges on this date is increased with one.

Routine Write.Result

This routine generate standard output reports on the average and the standard deviation of the length of stay (total, per DRG, per stage), the mean occupancy of each department and the different performance measures. Table 4.8. shows an example of the simulation output. The values of the different parameters are reset in function of a new data collection in the following iteration.

Table 4.8. An example of a simulation output report [53]

Simulation time	=	22560.0000
Average length of stay	=	412.6194 hours
Maximum length of stay	=	1260.2030 hours
Minimum length of stay	=	60.7134 hours
Standard deviation of length of stay	=	173.8730 hours
Average pre-operative length of stay	=	107.4444 hours
Standard deviation of preop LOS	=	97.3236 hours
Average surgical length of stay	=	72.3926 hours
Standard deviation of surgical LOS	=	49.8488 hours
Average post-operative length of stay	=	227.7367 hours
Standard deviation of postoperative LOS	=	149.2984 hours

Analysis per DRG

DRG CATEGORY	104	105	106	107
Pre-operative stage				
average	185.70	0.	0.	76.36
st.dev.	107.39	0.	0.	77.39
Surgical stage				
average	71.38	0	0	73.37
st.dev.	37.34	0.	0.	45.85
Post-operative stage				
average	225.490	0	0	228.83
st.dev	110.32	0	0	164.97
Total				
average	482.57	0	0	378.56
st.dev.	149.50	0.	0	174.72

[53] This report shows the results of the simulation during one run of 140 days.

```
============================================================================
DEPARTMENT 1
=============
Mean occupancy of the department :     2.29
DEPARTMENT 2
=============
Mean occupancy of the department :    14.40
DEPARTMENT 3
=============
Mean occupancy of the department :     1.16
DEPARTMENT 4
=============
Mean occupancy of the department :     3.78

THE AVERAGE NUMBER OF CHEST X- RAY PER STAY PER PATIENT:
=========================================================
preoperative stage            :     .59
surgical stage                :     .99
postoperative stage     :           .38

THE AVERAGE NUMBER OF DISCHARGES IN MPS FOR DRG 107:              1.354
THE MEAN % DEVIATION IN RX REQUIREMENTS /PERIOD:                  36.587  %
THE MEAN % DEVIATION IN BED REQUIREMENTS /PERIOD:                 14.560  %
THE MEAN DEV. BETWEEN REAL AND ORIGINAL DISCHARGE DATE:           4.801 days
THE MEAN DEV. BETWEEN REAL AND CURRENT DISCHARGE DATE:            4.801 days
THE AVG TIME BETWEEN ACTUAL AND PREFERRED ADMISSION DATE          0.     hrs
THE FRACTION OF TRANSFERS WHICH ARE BLOCKED:                      0.     %
PROP OF PREOP TIME DURING WHICH PATIENTS ARE BLOCKED:             0.     %
THE TOTAL NUMBER OF PATIENTS LEAVING THE HOSPITAL                 171    no.
THE STDEV OF THE UTILISATION OF DPT.8140:                         4.263
THE STDEV OF THE UTILISATION OF DPT.8327:                         1.791
THE MEAN UTILISATION OF DPT.8140:                                 14.729
THE MEAN UTILISATION OF DPT.8327:                                 3.764
==================================================================
```

Routine Write.MPS.Result (optional)

This routine allows to generate output reports on the different MPS schedules for DRG 104 and 107 for each replanning period and for a length equal to the planning horizon (see table 4.11. in section 4.5.4.1.). The daily actual and planned resource consumption statistics are also displayed.

Routine Operating.Room.Dat

This routine is designated to generate an output report with different frequency distributions: a frequency distribution about the number of admissions per day, about the classification of patients in the DRG categories and about the number of discharges scheduled on the MPS each day during each MRP explosion.

Routine Write.Trace.Line

This routine traces the patient during his/her flow through the hospital. It is introduced because of validation purposes (see further).

Routine Write.Trace.Day

This routine allows to trace a patient as to his/her scheduling date in the MPS. This routine is a validation routine.

Routine Write.Trace.MPS

This routine allows to trace the number of patients scheduled (in a certain stage) at the moment of changes in the scheduling process. This is also a validation routine.

Function Rtot.F(.number)

This function is needed in the trace routines.

4.5.4. Verification and validation of the simulation model

Figure 4.4. gives an overview of the different steps necessary to build a valid and credible simulation model (Law et al., 1991, p.299). In this part we focus on the problem of verification and validation.

4.5.4.1. Verification

Verification is determining that a simulation computer program performs as intended (Law et al., 1991, p.299). There are two broad categories of verification tasks (McHaney, 1991, p.106): preventive verification and appraisal verification. The two most important tasks in preventive verification are careful documentation and structured programming. The description of the simulation model in the previous section (and in appendix 8) clearly shows that a structured programming approach is used. The whole program has been built using many different modules which can be tested individually. Furthermore we have started with a moderate detailed model and gradually increased the complexity of the model. The detailed description of the model in appendix 8 and the description of the assumptions underlying the model (see further in this section) are part of the documentation efforts.

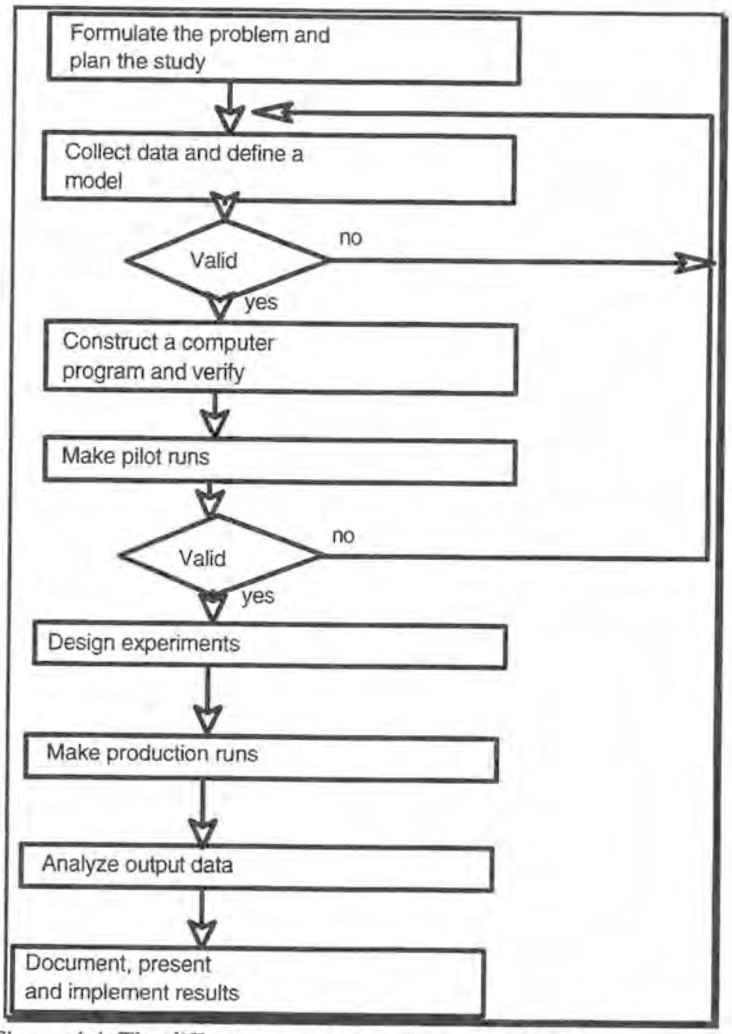

Figure 4.4. The different steps in simulation modelling.

Appraisal verification is done to check (debug) the programming after it has been coded (McHaney, 1991, p.107). Several verification techniques are available (see Law et al., 1991, pp. 302-303 and McHaney, 1991, p.107). One of the most powerful techniques is to perform a "trace" (Sargent, 1987; Law et al., 1991, p. 303). In a trace, the whole history of events for a particular entity (e.g. a particular patient) is registered. Table 4.9. shows a part of one of the trace files used for this model. 6408 hours after starting the simulation a demand for hospital admission is generated by patient number 338. The patient has an emergency status and is assigned to category 104. Based on a predetermined length of stay, the discharge date of the patient is scheduled in the DRG 104 master production schedule. The patient is immediately admitted (emergency !) on department 2191, i.e. cardiology. Based on his/her destination, the patient is put in a certain matrix cell of the transition probability matrix. Matrix cell 5 means that the patient in the next stage goes to the preoperative medical heart surgery department (8140)[54]. While the patient is in the 2191 department, consumption of chest X-ray is registered. After

[54] This is the same as the matrix cell (1,2) in table 3.1.in section 3.3..

some time the patient is transferred to the 8140 department where she/he is put in matrix cell 10 (i.e. destination department 8327)[55]. It is possible to read the whole file in this way and to discover logical flaws in the program.

In another trace file (table 4.10.), the changes in the Master Production Schedule are traced. It indicates the scheduling of the discharge date of a new patient (scheduled DUE DATE) and the rescheduling of the discharge date of a patient at the moment that planned and actual preoperative length of stay are compared. The original number of gross requirements on a certain date is reduced with one when a patient is rescheduled (-1). The number of gross requirements on the newly scheduled discharge date is increased with one (+1).

Table 4.9. A part from the trace file of the patient flow.

6408.0000 patient 338 patient emergency
6408.0000 patient 338 patient is emergency
6408.0000 patient 338 arrival queue
6408.0000 patient 338 patient in MPS.DRG104
6408.0000 patient 323 patient leaves OR check by admission
6408.0000 patient 291 patient is admitted
6408.0000 patient 291 patient leaves arrival queue
6408.0000 patient 291 patient in department 8140
6408.0000 patient 291 patient in matrix 10
6408.0000 patient 338 patient is admitted
6408.0000 patient 338 patient leaves arrival queue
6408.0000 patient 338 patient in department 2191
6408.0000 patient 338 patient in matrix 5
6408.0000 patient 338 patient: RX in DPT.2191
6409.4739 patient 278 patient: RX in DPT.8140
6409.4739 patient 278 patient out matrix 31
6409.4739 patient 278 patient is leaving the hospital
6412.2386 patient 331 patient out matrix 15
...
6456.0000 patient 323 patient is admitted
6456.0000 patient 323 patient leaves arrival queue
6456.0000 patient 323 patient in department 2191
6456.0000 patient 323 patient in matrix 5
6456.0000 patient 323 patient: RX in DPT.2191
6519.5863 patient 338 patient: RX in DPT.2191
6519.5863 patient 338 patient out matrix 5
6519.5863 patient 338 patient in department 8140
6519.5863 patient 338 patient in matrix 10
6519.5863 patient 338 patient: RX in DPT.8140
...
6572.7906 patient 338 patient: RX in DPT.8140
6572.7906 patient 338 patient out matrix 10
6572.7906 patient 338 patient in the department queue before 8327
6572.7906 patient 338 patient in department 8327
6572.7906 patient 338 Rx for patient in 8327

55 This is the same as the matrix cell (2,4) in table 3.1. in section 3.3.

```
6572.7906 patient 338 patient in matrix 15
...
6638.7367 patient 323 patient: RX in DPT.8140
6638.7367 patient 323 patient out matrix 10
6638.7367 patient 323 patient in the department queue before 8327
6638.7367 patient 323 patient in department 8327
6638.7367 patient 323 MPS is to be changed
6638.7367 patient 323 yes
6638.7367 patient 323 discharge date DRG 104 is changed
6638.7367 patient 323 Rx for patient in 8327
6638.7367 patient 323 patient in matrix 15
..
6679.1065 patient 338 patient out matrix 15
6679.1065 patient 338 patient in department 8140
6679.1065 patient 338 patient in matrix 31
6679.1065 patient 338 patient: RX in DPT.8140
...
6837.8135 patient 338 patient: RX in DPT.8140
6837.8135 patient 338 patient out matrix 31
6837.8135 patient 338 patient is leaving the hospital
```

Table 4.10. A part of the trace file following the changes to the MPS

```
6600.0000 day278 346  controle
6600.0000 day288 346 Scheduled DUE DATE of DRG107
6600.0000 day314 347 scheduled DUE DATE of DRG104
6600.0000 day304 348 Scheduled DUE DATE of DRG107
6622.7119 day288 346 -1
6622.7119 day286 346 +1
6624.0000 day279 349  controle
6624.0000 day289 349 Scheduled DUE DATE of DRG107
6624.0000 day329 350 Scheduled DUE DATE of DRG107
6638.7367 day284 323 -1
6638.7367 day285 323 +1
6648.0000 day280 351  controle
6648.0000 day284 352 controle
6648.0000 day290 351 Scheduled DUE DATE of DRG107
6648.0000 day295 352 scheduled DUE DATE of DRG104
6651.8846 day286 345 -1
6651.8846 day287 345 +1
6652.8916 day289 349 -1
6652.8916 day287 349 +1
6672.0000 day318 353 scheduled DUE DATE of DRG104
6672.0000 day304 354 Scheduled DUE DATE of DRG107
6676.0911 day286 333 -1
6676.0911 day284 333 +1
6679.1065 day290 351 -1
6679.1065 day288 351 +1
6692.6363 day288 337 -1
6692.6363 day286 337 +1
```

Using the two trace files, it is possible to further verify the program. For instance in the first trace file, it is indicated at time 6638.7367 that for patient 323 the MPS is to be changed. This patient has been admitted at time 6456. The difference between the two time indications is (6638 - 6456) = 182 hours. The standard (average) preoperative length of stay is 168 hours or 7 days.

The difference between the actual length of stay and the planned length of stay is approximately 14 hours. This is considered as 1 day in the planning system. Because the actual preoperative length of stay is greater than the planned one, the discharge date of this patient must be shift forward one day (from day 284 to day 285 in table 4.10 for patient 323). Remark that this kind of verification also increases the validity of the model.

We have also generated some Master Production Schedules using a one day planning interval. Table 4.11. shows the master production schedule generated on time 6624 (i.e. for day 275) and on time 6648 (i.e. day 276)[56]. The changes in the MPS generated on day 276 (as compared with day 275) must be found in the trace file of the MPS changes. If we compare the gross requirements in each of the MPS tables, we see that changes have been made on day 284, 285 and 289. In the trace file we observe that between time 6624 and 6648, the discharge date for a new DRG 107 patient has been scheduled for day 289 and the discharge date of another patient (number 323) has been rescheduled from day 284 to day 285 [57].

Table 4.11. MPS/MRP table for two selected days

CURRENT DAY = DAY 275

DAY	GR		PRE		SURG		POST		E	A	(*)
	104	107	104	107	104	107	104	107			
275	0	1	0	4	3	2	2	6	11.10	8.00	
276	0	4	0	5	2	1	3	6	9.84	0.	
277	1	1	0	2	1	3	4	3	8.44	0.	
278	0	0	0	1	0	4	4	2	7.47	0.	
279	0	0	0	0	0	2	4	5	5.87	0.	
280	0	0	0	1	0	1	4	6	5.73	0.	
281	0	0	0	2	0	0	4	7	5.58	0.	
282	1	0	0	2	0	0	4	7	5.58	0.	
283	1	1	0	1	0	1	3	7	5.73	0.	
284	1	1	0	0	0	2	2	6	5.47	0.	
285	1	0	0	0	0	1	1	6	3.95	0.	
286	0	3	0	0	0	0	0	7	2.83	0.	
287	0	1	0	0	0	0	0	4	1.62	0.	
288	0	1	0	0	0	0	0	3	1.21	0.	
289	0	0	0	0	0	0	0	2	.81	0.	
290	0	0	0	0	0	0	0	2	.81	0.	
291	0	0	0	0	0	0	0	2	.81	0.	
292	0	1	0	0	0	0	0	2	.81	0.	
293	0	1	0	0	0	0	0	1	.40	0.	
294	0	0	0	0	0	0	0	0	0.	0.	
295	0	0	0	0	0	0	0	0	0.	0.	

[56] The planning horizon used in these examples is 20 days. In the final experiments, we use a planning horizon of 35 days.
[57] It can be verified somewhere else in the trace file that patient 323 is a DRG 104 patient.

CURRENT DAY = 276

DAY	GR 104	GR 107	PRE 104	PRE 107	SURG 104	SURG 107	POST 104	POST 107	E	A
276	0	4	0	5	2	1	3	6	9.84	9.00
277	1	1	0	3	2	3	3	3	9.72	0.
278	0	0	0	2	0	4	4	2	8.04	0.
279	0	0	0	1	0	2	4	5	6.44	0.
280	0	0	0	1	0	2	4	6	6.85	0.
281	0	0	0	2	0	1	4	7	6.70	0.
282	1	0	0	2	0	0	4	8	5.99	0.
283	1	1	0	1	0	1	3	8	6.13	0.
284	0	1	0	1	0	2	2	7	6.44	0.
285	2	0	0	1	0	1	2	7	5.32	0.
286	0	3	0	1	0	0	0	8	3.80	0.
287	0	1	0	0	0	1	0	5	3.14	0.
288	0	1	0	0	0	1	0	4	2.73	0.
289	0	1	0	0	0	0	0	4	1.62	0.
290	0	0	0	0	0	0	0	3	1.21	0.
291	0	0	0	0	0	0	0	3	1.21	0.
292	0	1	0	0	0	0	0	3	1.21	0.
293	0	1	0	0	0	0	0	2	.81	0.
294	0	0	0	0	0	0	0	1	.40	0.
295	0	0	0	0	0	0	0	1	.40	0.
296	0	1	0	0	0	0	0	1	.40	0.

(*) PRE/SURG/POST = total number of patients in this stage on this day
GR = Gross requirements (scheduled discharge date)
E = Estimated resource consumption on this day
A = Actual resource consumption on this day

Table 4.11. also shows the results of the MRP explosion. It can be verified whether the planned resource consumption is calculated in the right way when the predetermined standard units are known. In this particular example, a patient consumes daily 0.5694 chest X-ray units in the preoperative stage, 1.1185 chest X-ray units in the surgical stage and 0.4040 units in the postoperative stage [58]. For instance for the first day (276) in the second MPS, we can recalculate the (planned) consumption of chest X-rays of the patients remaining in a particular stage on this day:

preoperative: 5 patients x 0.5694 = 2.847
surgical: 3 patients x 1.1185 = 3.3555
postoperative: 9 patients x 0.4040 = 3.636

Total planned consumption of chest X-rays = 9.8385

This calculated value is clearly the same as the 9.84 value in the estimated consumption column of the MPS table.

[58] These results have been obtained from one of the output reports in one of the simulation runs.

In the same way it can be verified whether gross to net offsetting is performed in the right way. Table 4.12. shows the standard length of stay units used in the planning system in one simulation run. For instance the DRG 107 patient with discharge date on day 296 (gross requirements) stays 8 days in the postoperative stage (from day 289 (morning) until day 296 (evening)), 2 days in the surgical stage (days 287-288) and three days in the preoperative stage (from day 284 until day 286).

Table 4.12. The standard length of stay units used in the example [59]

Stage/ DRG number	Standard length of stay in days
preoperative DRG 104	7
surgical DRG 104	3
postoperative DRG 104	8
preoperative DRG 107	3
surgical DRG 107	2
postoperative DRG 107	8

4.5.4.2. Validation

Validation is concerned with the question whether the conceptual model is an accurate representation of the system under study (Law et al, 1991, p.299). "If a model is "valid", then the decisions made with the model should be similar to those that would be made by physically experimenting with the system (if this is possible)" (Law et al., 1991, p.299). Testing of the validity of the conceptual model includes two different steps (Sargent, 1987): (1) obtaining face validity and (2) testing of the assumptions of the underlying model.

Face validity can be obtained through several mechanisms (see Law et al., 1991, pp. 308-309). In this study, we have tried to obtain face validity through observation of the working of the heart surgery department in the hospital and through several conversations with nurses and physicians ('system experts'). A very detailed study of different databases available in the hospital contributed to a better knowledge of the system. One example is the creation of the chart in figure 4.5. showing the flow of cardiac surgery patients through different departments in the hospital. This chart is based on a detailed analysis of the admission/discharge/transfer database of the hospital. For instance, it can be observed that respectively 114, 200, 47 and 3 patients have department 2191D, 8140C, 8325D as admitting department. Another example is the characterisation of the patient population in this unit. Table 2.4. (in section 2.2.) shows such a profile. This profile is based on the Minimal Clinical Data set.

[59] These standard units are based on data collected during the simulation. This means that they will differ for different simulation runs.

While using databases, another problem of validity emerges, i.e. data validity. Afterwards, we have discussed the results of this data analysis with several people (the CEO, the head of the Medical Informatic department).

Another technique to obtain face validity is tracing (the same technique as used in verification) (Sargent, 1987). The trace of an entity (patient) during his/her stay in the hospital can help accepting the logic behind the model.

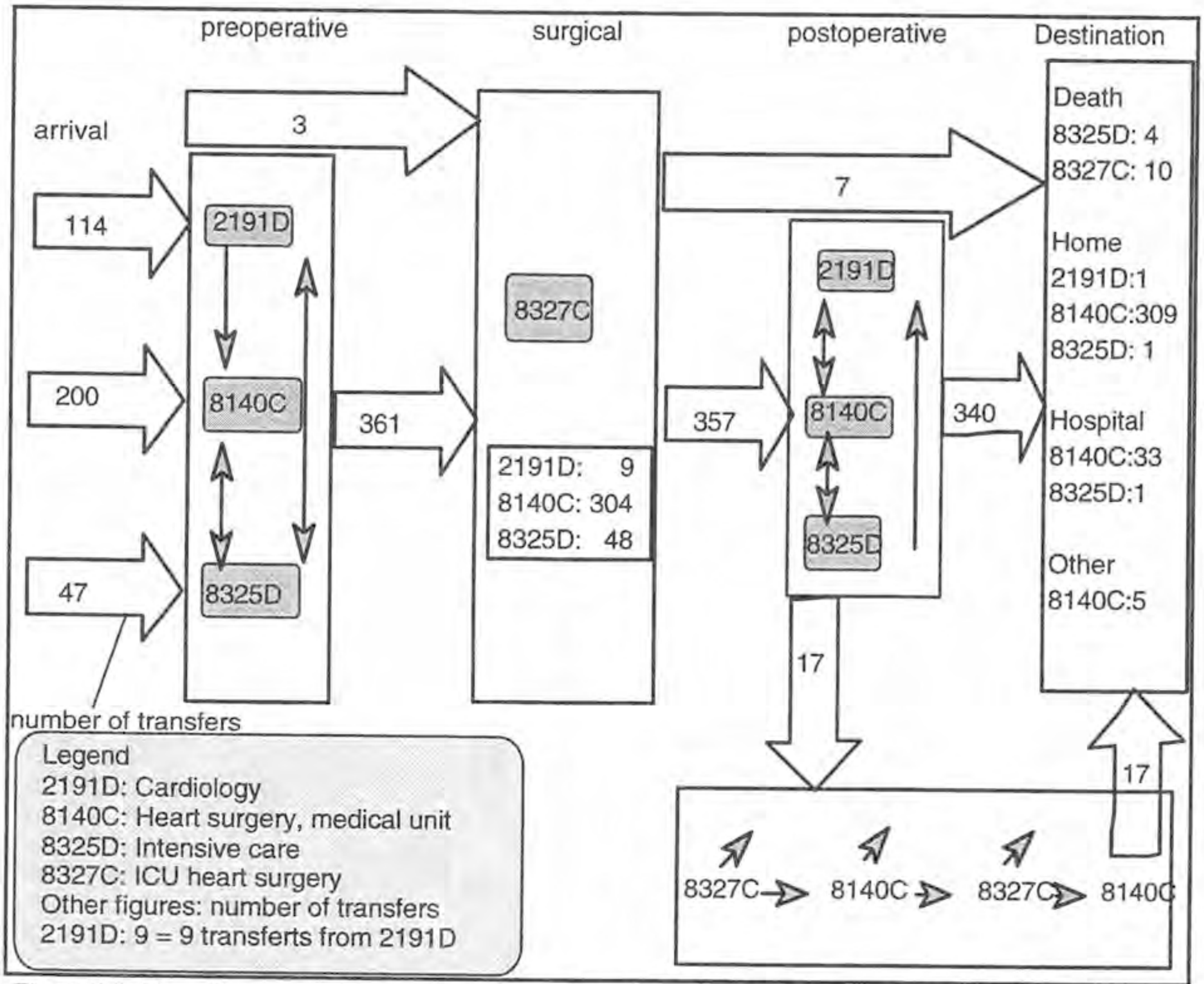

Figure 4.5. Flow diagram for 364 heart surgery patients treated in a Belgian hospital in 1992.

In the second step, it is important to test the assumptions made during the model development. In testing the assumptions, a distinction is made between the shop level and the planning level of the model.

4.5.4.2.1. The shop level

As to the shop level, we have made the following assumptions:

1. Demand for hospital admission is generated by a Poisson distribution with a mean equal to 1.29

The demand for hospital admission is considered as an arrival process for which the inter arrival times (or the time between two subsequent arrivals) are independent distributed exponential random variables. In other words, we assume that the (first) demand for hospital admission of one patient is independent from the demand for hospital admission of another patient. When the inter arrival time between the occurrence of any one event until the occurrence of the next has an exponential distribution, then the events occur according a Poisson distribution (Scheaffer, 1990, p.152). It is common practice to model such an arrival process using a Poisson distribution (Law et al., 1991, p.405). The parameter of the Poisson distribution is nothing else than the mean of the data. [60] Figure 4.6. shows the fitting of a 'theoretical' Poisson distribution on the empirical data on the number of demands for admission per day. We have used the dates on which patients receive catheterisation as the dates of first demand for admission.

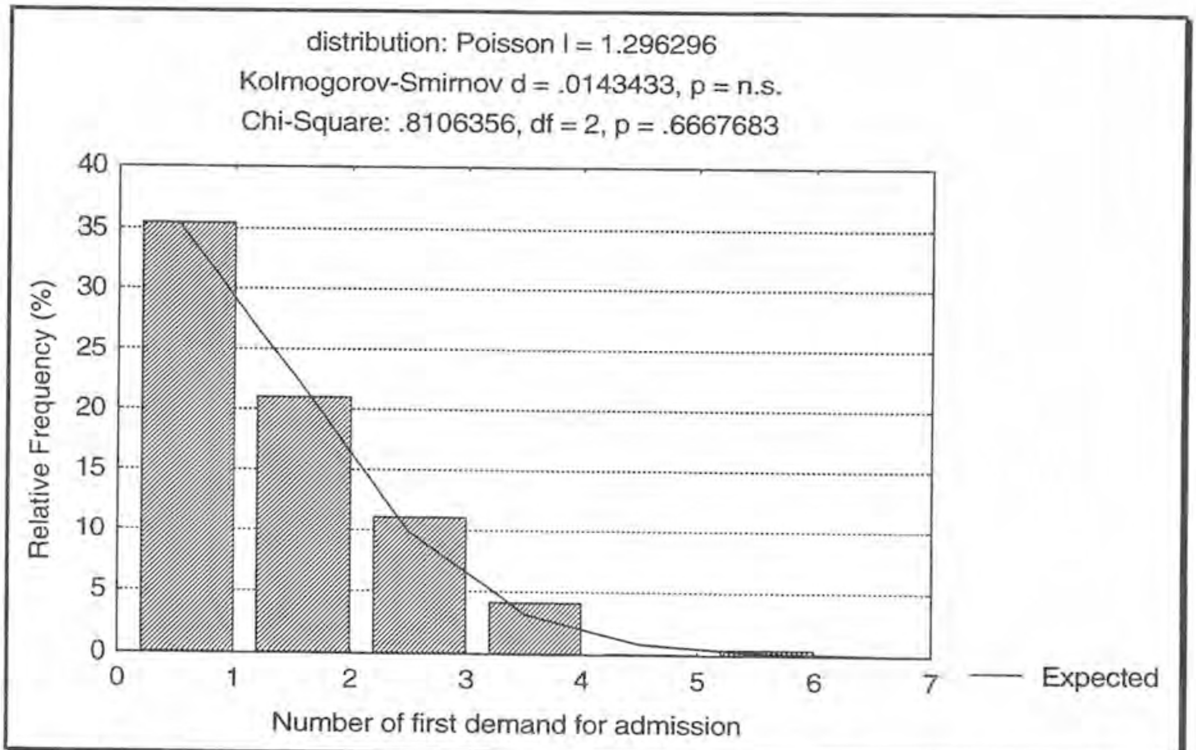

Figure 4.6. Fit between the empirical distribution of the number of first demand for admission and a Poisson distribution. (162 patients).

[60] The mean of this distribution is a maximum-likelihood estimator of the parameter from the data (Law et al., p.349).

In the next step, we have to determine the goodness of fit of the theoretical Poisson distribution compared with the empirical data. The chi-square test and the Kolmogorov-Smirnov test are commonly used for distribution fitting (Thesen et al., 1992). The Kolmogorov-Smirnov test is primarily intended for use with continuous distributions (Thesen et al., 1992, p.150). Because in this particular case, the distribution is discontinuous, we use the chi-square test.
Because STATISTICA [61] automatically takes the categories with less than 5% frequency together until a category with more than 5% can be formed, categories 4, 5 and 6 are collapsed with category 3. So three categories remain. With (3-1) or 2 degrees of freedom, the critical value for a 95% confidence level is 5.99 (see table in appendix 9). Because the calculated value of 0.81 is much smaller than the critical value, the null hypothesis (that the data set was drawn from a Poisson distribution) cannot be rejected. In figure 4.6., it is shown that there is a 67% likelihood that a chi-square distributed random variable with two degrees of freedom is greater than 0.81. So it is very likely to see a chi-square value of 0.81 or higher simply due to chance even when the assumed distribution is correct. This reinforces our belief that the data set was indeed drawn from the assumed distribution.

2. Time between demand for admission and admission for elective patients is a lognormal distribution with mean equal to 22.5 days and standard deviation of 17.01 days.

The empirical data on the number of days between the two events is described in table 4.13.

Table 4.13. The empirical distribution of the number of days between demand for admission and actual admission. The characteristics of this distribution.

Category	Count	Percent	Cumulative percent
0.0 - 8.2	21	0.13	0.13
8.2 - 16.4	47	0.29	0.42
16.4 - 24.6	46	0.28	0.70
24.6 - 32.8	23	0.14	0.84
32.8 - 41.0	6	0.04	0.88
41.0 - 49.2	4	0.02	0.90
49.2 - 57.4	4	0.02	0.92
57.4 - 65.6	5	0.04	0.96
65.6 - 73.8	2	0.01	0.97
73.8 - 82.0	2	0.01	0.98
82.0 - 90.2	2	0.01	0.99
			1.00

Mean	= 22.4
Median	= 18.0
Std.dev	= 16.5
Skewness	= 1.88

[61] Statistica is the software package that we have used in the analysis.

We have used the technique of distribution fitting to find a theoretical distribution for modelling this phenomenon. In order to find the best fitting distribution, we have used the distribution fitting module of the Simfactory/Simprocess package (CACI, 1992). This module finds that a lognormal distribution with a mean of 2.89 and a standard deviation of 0.67 best fits the empirical data [62].

Because of the continuity of the data, we have used a one-sample Kolmogorov-Smirnov test to evaluate the goodness of fit. This test compares an observed sample distribution with a theoretical distribution. We determine the point of greatest divergence between the observed (cumulative) frequency distribution and the theoretical (cumulative) frequency distribution. We identify this value as d (Emory, 1991, p.569). From a table of critical d-values, we determine whether such a divergence is likely on the basis of random sampling variations from the theoretical distribution. In this particular case, we have calculated d using STATISTICA (Statsoft, 1994). The calculated d value is 0.056 (see figure 4.7.). The critical value with $n = 162$ and $\alpha = 5\%$ is (see table in appendix 9):

$$\text{critical value} = \frac{1.36}{\sqrt{162}} = 0.10658$$

Because the calculated value is smaller than the critical value, we could not reject the null hypothesis that the data set was drawn from the specified theoretical distribution.

[62] In number of days, the mean is 22.5 and the standard deviation is 17.01.

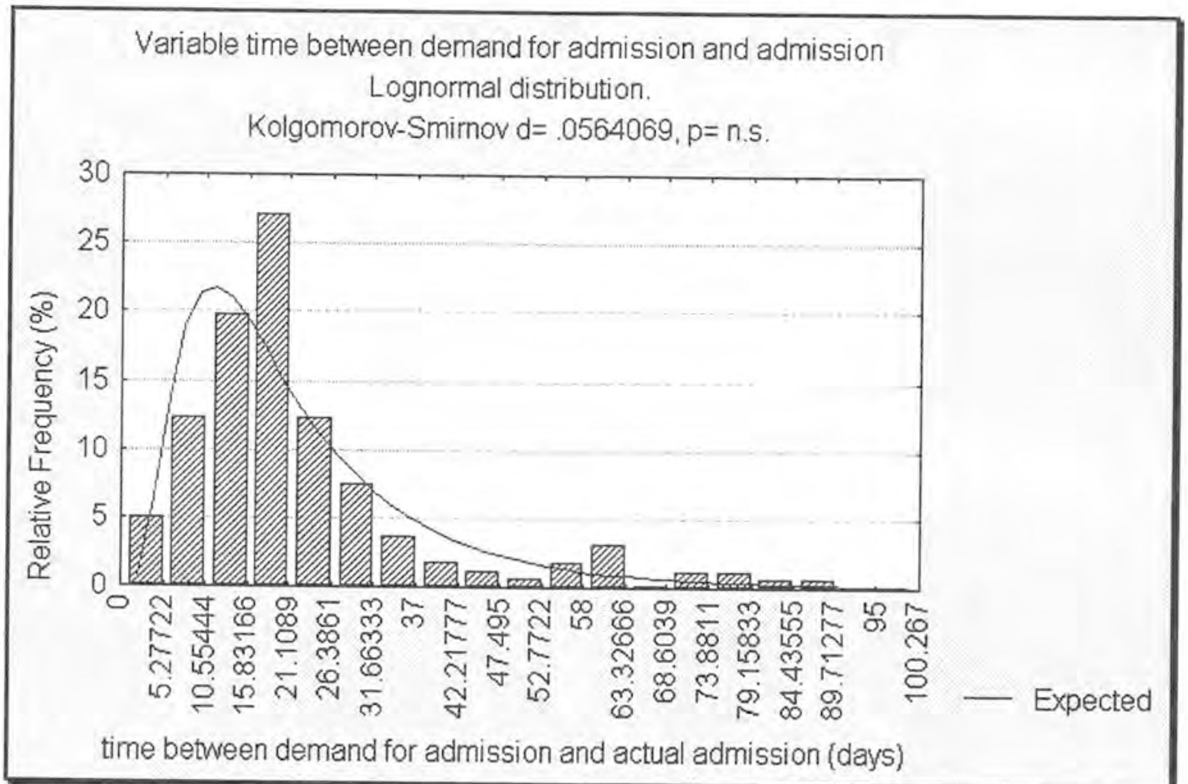

Figure 4.7. Fit between the empirical distribution of the time between first demand for admission and actual admission and a lognormal distribution.

3. The flow of patients through the network of service units can be folded in a compact form through the use of a transition-probability matrix and behind each cell of the transition-probability matrix, there is a unique length of stay distribution.

We have already indicated earlier that this is one of the key assumptions of the model. The process flow of patients through the hospital is driven by state transition probabilities and a set of holding time probability distributions for every possible transition. Thus the patient flow through the network of service units is considered as a specific stochastic process, more specifically a Markov process model (Weiss, 1980, p.20). Markov process models are similar to Markov chains except that it is assumed that the time spent in any one state [63], given that the patient will be transferred to another is a random variable (Weiss, 1980, p.20). One of the key assumptions of a Markov chain is that each transition is independent from the past history of the process (Scheaffer, 1990, p.113). Several authors have used this kind of stochastic process to model the patient flow in coronary care units (Thomas, 1968; Kao, 1972 and 1974; Cohen, 1980). It is necessary to test in this particular case whether transition probabilities or holding

[63] State is based on the care unit in which the patient resides (like in Kao, 1974).

time distributions are independent of the previous locations of the patient. Nonetheless, a very long (iterative) procedure is needed to test Markov assumptions (Weiss et al., 1982). We do not believe that testing of these assumptions contributes to the value of our study. We do not use Markovian based analytical models to obtain results.

4. The distribution of the length of stay for patients in the matrix cells (1,2), (2,4), (4,6) are normal and for patients in the matrix cell (6,20) lognormal.[64].

Based on the empirical length of stay distributions, it was not possible to fit a theoretical distribution. The main cause of the lack of goodness of fit can be due to the small number of cases in most cells of the transition probability matrix. Because generalisation is not really important in this study, we could have used the empirical distributions for all matrix cells. Nonetheless, we want to introduce length of stay variability as a research variable. This can only be accomplished by using a theoretical distribution (with a standard deviation as one of the parameters)[65]. When studying the data of the different length of stay distributions in specific departments, we found a very strong positive skewness in most of the data (see figures 4.8.-4.11 for the length of stay distributions of the four high volume matrix cells). In each department, there are some outliers with extremely long length of stay. In this study, it is important to include these outliers because it is an aspect contributing to uncertainty. Based on this observation, the lognormal distribution (with a mean and a standard deviation) seems to be a useful distribution in this study. An advantage of the lognormal distribution is that the coefficient of variation can be smaller and greater than one. When the coefficient of variation is greater than one, then some very extreme values can occur (Hillen, 1993, p. 120). To calculate the parameters of the lognormal distributions, we have transformed the data using the natural logarithms.

Allowing the theoretical distribution to be lognormal in any of the four (high volume) matrix cells creates the possibility of observing patients with an unrealistic long total length of stay because of the cumulation of extremely long length of stay of the same patient in different matrix cells (departments). To avoid such behaviour, only the length of stay on the department 8140C (matrix cell (6,20)) is modelled as a lognormal distribution. In the other instances, a normal distribution is used with a cap on the minimum value which is allowed to occur. When values are generated below this minimum in matrix cells (2,4) and (4,6), they get the value of the mode (empirically observed) in order to better model the high peak on this mode value (see figures 4.9. and 4.10) . In the case of matrix cell (1,2), the minimum value is retained (see figure 4.8 and also table 4.14).

[64] In these brackets, 1= 2191D or cardiology preoperative; 2 = 8140C or heart surgery, medical, preoperative, 4= 8327C or intensive care heart surgery, 8140CO = heart surgery, medical, postoperative.

[65] We have already indicated that leadtime uncertainty is introduced by varying the standard deviation of the distributions.

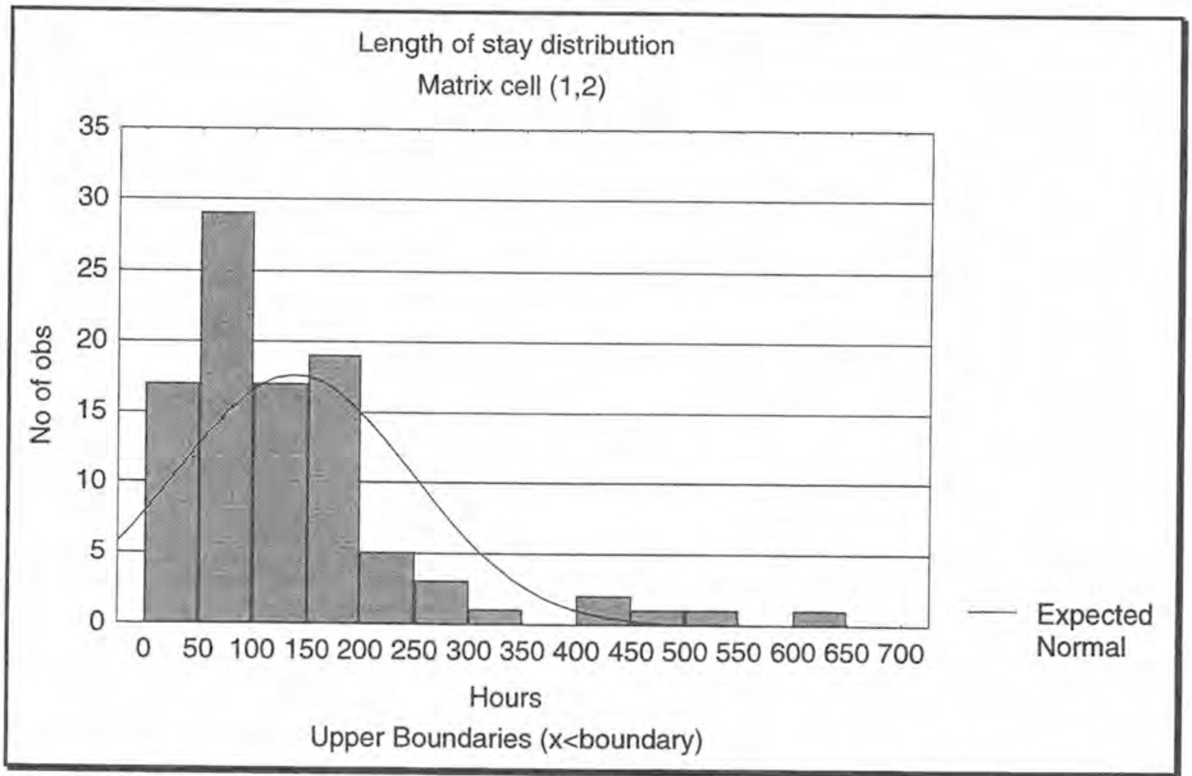

Figure 4.8. The length of stay distribution in matrix cell (1,2) (96 patients)

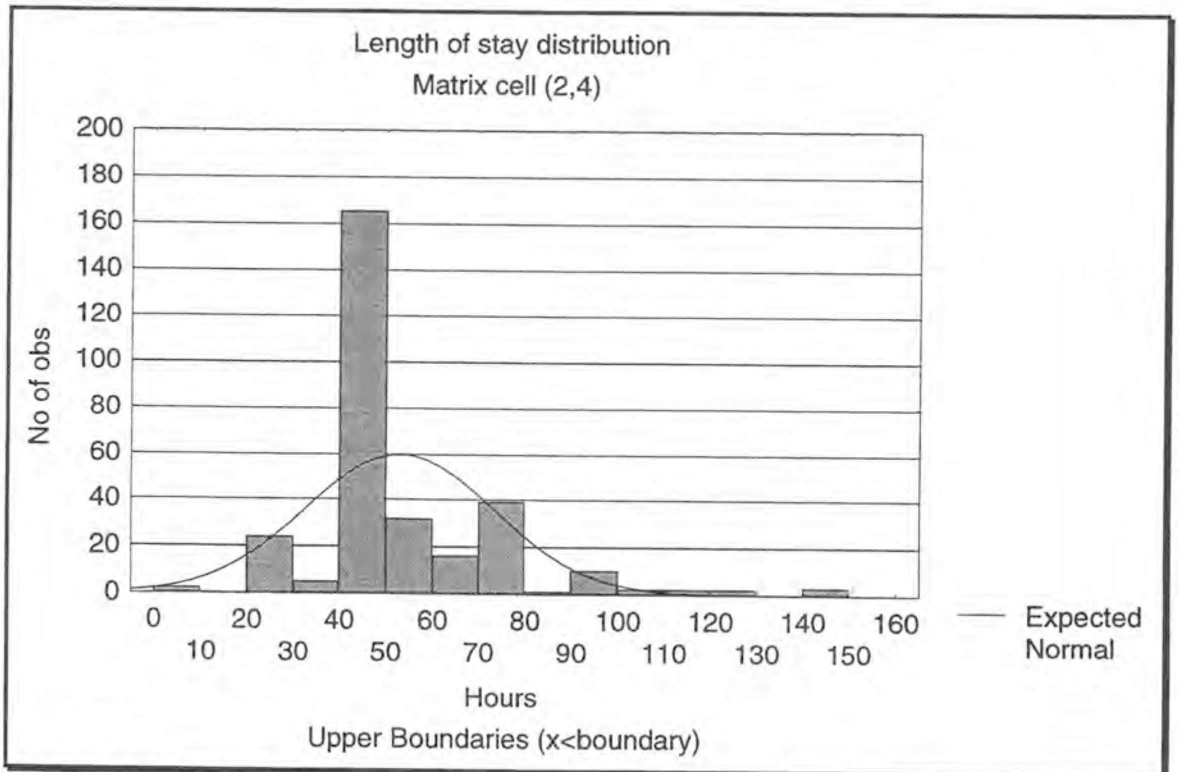

Figure 4.9. The length of stay distribution of matrix cell (2,4) (304 patients)[66]

[66] 1 outlier with a lenght of stay of 739 hours has been excluded to limit the length of the X-axis.

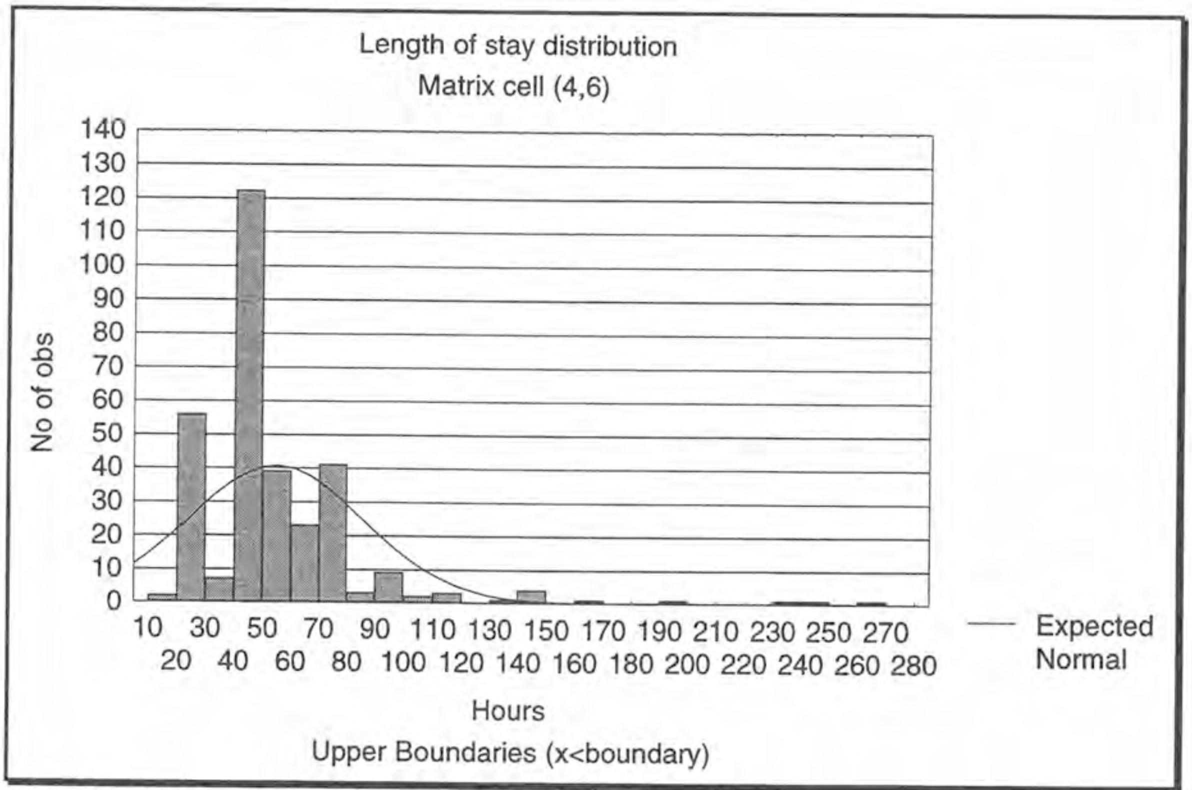

Figure 4.10. The length of stay of matrix cell (4,6) (319 patients)[67]

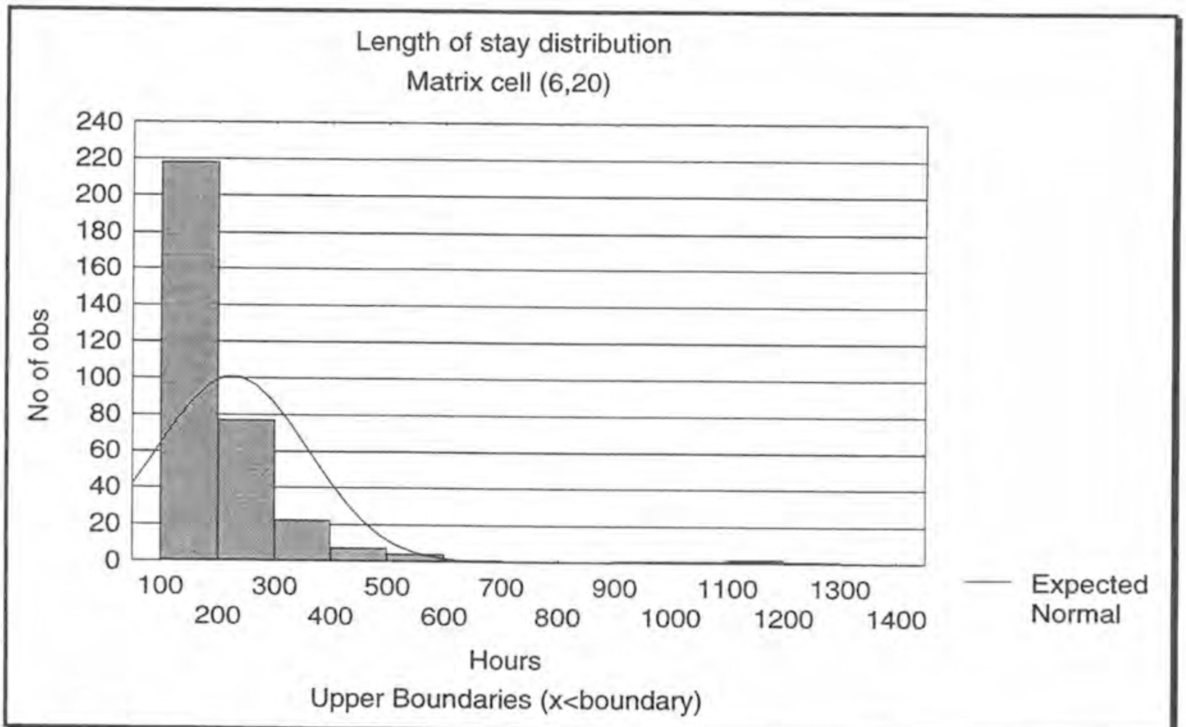

Figure 4.11. The length of stay distribution of matrix cell (6,20) (334 patients)

[67] 2 outliers with a lenght of stay of 460 hours and 795 hours have been excluded.

Table 4.14. The parameters of the lognormal and normal distributions of the different high-volume matrixes [68]

Location	n	distribution	Mean	Standard deviation	Minimum	Mode value
Matrix cell (1,2) (department 2191)	96	normal	138 *	109	3	n.a.
Matrix cell (2,4) (department 8140 preoperative)	304	normal	55	44	1	45
Matrix cell (4,6) (department 8327)	319	normal	58	56	13	45
Matrix cell (6,20) (department 8140 postoperative)	334	lognormal	5.34 **	0.57 (**)	n.a.	n.a.

(*) in hours
(**) this corresponds with a mean of 245 hours and a standard deviation of 152 hours.
n.a. = not applicable

Figure 4.12. shows a comparison of the distribution of the total length of stay of the patients in the simulation and the empirical total length of stay distribution. When testing the null hypothesis that the two samples are drawn from the same population using a two-sample Kolgomorov- Smirnov test, we find that the null hypothesis could be rejected at $\alpha = 0.05$ level. When we compared the means of both distributions using a Z-test for two independent samples [69](Emory, 1991, p.539), we find that the null hypothesis that both means are equal could not be rejected (see table 4.15). For the variance, we perform no test because the variance is introduced as a parameter in the model (so that the variance of the distribution of the simulated length of stay data can be made more or less equal to the variance of the empirical distribution).

We find that the equality in means is a sufficient condition to accept the proposed theoretical distributions, although we are aware of the fact that the length of stay distribution used in the simulation does not completely describe the behaviour of the empirical data.

Table 4.15. Tests for the means of a simulated and the observed length of stay distribution

	Simulation	Empirical	Z-value
Number of cases	1262	364	
average LOS	398	391	0.46
critical value			1.96 (*)

(*) two-tailed test, $\alpha = 0.05$, standard normal distribution.

[68]Remark that the mean and the standard deviation of these lognormal distributed are obtained by using maximum-likelihood estimators for estimating the parameters from the data (see Law et al., 1991, p.337).
[69] The Z-test is preferred above the t-test because of the large sample sizes.

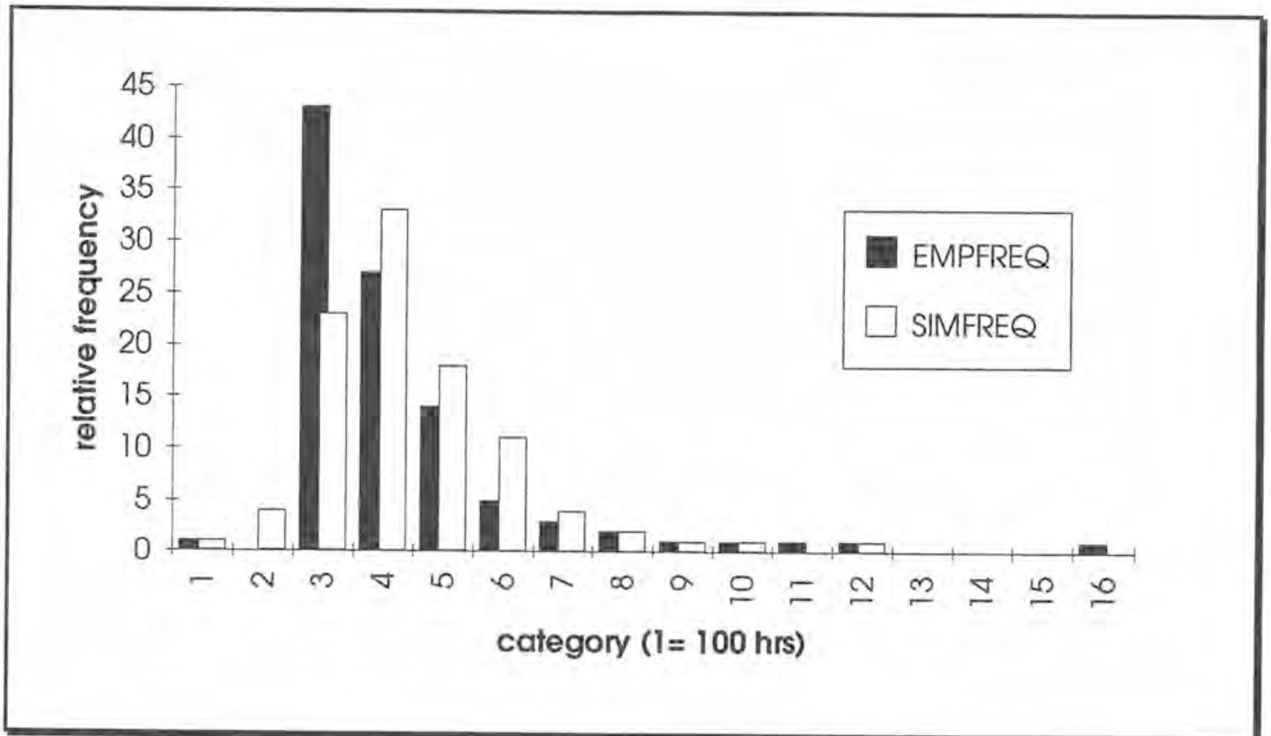

Figure 4.12. A comparison of a length of stay distribution in the simulation model and the empirical length of stay distribution.

5. The distribution of the length of stay for patients in all the other cells is equal to the empirical observed distribution.

The number of data points in each of the other cells is too small to fit theoretical distributions. When the sampling distributions cannot be characterised by one of the statistical distributions, a table look-up procedure to sample variables can be used. A table look-up procedure has a list of possible numerical values together with their associated probabilities. It selects a sample value by generating a random number and matching it against the possible probability values. As an example, table 4.16 shows the cumulative distribution of the length of stay in matrix cell (1,4). Sampling is performed by generating a random number, matching it with a value in column 1, and selecting an appropriate value from column 2. Interpolation is done between the column 2 value associated with the stopping probability and the column 2 value preceding it. (CACI, 1992, pp. 258-259). We say that random linear variables are used to sample. [70]

[70] In the case of random step variables, interpolation does not occur.

Table 4.16 Sampling distribution (example)

Cumulative distribution	Sample value (LOS in hours)
0.00	0
0.33	19
0.66	27
1	161

4.5.4.2.2. The planning level

The assumptions underlying the HSRP system are heavily based on the assumptions of a MRP system. In other words using a MPS (as shown in table 4.11.) with the DRG specific bill of resources in a real MRP system should give the same results. Table 4.17 shows the results of a MRP explosion of the MPS table for day 276 in table 4.11. using a MRP simulator of the seminar of Industrial Management of the University of Gent (Van Landeghem, 1994). In this explosion, all patients currently in stage are scheduled as 'orders due' or scheduled receipts'. This explosion allows to validate the working of the MRP system in our simulation model. For instance the patient scheduled to be discharged on day 296 is gross and net requirements in the MPS table. Because the postoperative lead-time is 8 days, the entry of the patient in this stage must be at day 288 or the net requirements of the previous surgical stage must be at least 1 on this day. With a surgical length of stay of 2 days, the patient must leave the preoperative stage on day 286. To achieve this date, he must be admitted at day 283, taking into account a preoperative length of stay of 3 days. There are 12 scheduled receipts (or orders due). This means that there are 12 DRG 107 patients which are in the post-operative, preoperative or surgical stage at day 276: 6 patients in the postoperative stage, 1 patient in the surgical stage and 5 patients in the preoperative stage. This can be checked with the first line in the MPS/MRP tables in table 4.11.

Table 4.17. MRP tables DRG 107 patients

MRP table postoperative stage DRG 107 patients

		276	277	278	279	280	281	282	283	284	285
GR[71]		4	1						1	1	
OD		4	1						1		
OH											
NR										1	
PO		1		3	1	1	1			1	1

	286	287	288	289	290	291	292	293	294	295	296
GR	3	1	1	1			1	1			*1*
OD											
OH											
NR	3	1	1	1			1	1			*1*
PO			*1*								

MRP table surgical stage DRG 107 patients

		276	277	278	279	280	281	282	283	284	285
GR		1		3	1	1	1			1	1
OD		1									
OH											
NR				3	1	1	1			1	1
PO		3	1	1	1			1	1		

	286	287	288	289	290	291	292	293	294	295	296
GR			*1*								
OD											
OH											
NR			*1*								
PO	*1*										

MRP Table Preoperative stage DRG 107 patients

		276	277	278	279	280	281	282	283	284	285
GR		3	1	1	1			1	1		
OD		3	1	1							
OH											
NR					1			1	1		
PO		1			1	1			**1**		

	286	287	288	289	290	291	292	293	294	295	296
GR	*1*										
OD											
OH											
NR	*1*										
PO											

GR = gross requirements
OD = orders due or scheduled receipts
OH = orders on hand
NR = net requirements
PO = planned order

[71] These gross requirements are the same as the gross requirements in table 4.11.

4.5.5. Statistical analysis of the output of a simulation model

When analysing the output of a simulation study, it is important to make a distinction between different types of simulation (Kleijnen, 1987; Verdini, 1993; Law et al., 1991, pp. 527): the simulation of a terminating system or the simulation of a steady state (or a non-terminating) system. A terminating system is one with a clearly identifiable event beyond which no useful information can be obtained or with a time point at which the system is cleaned out (Law et al., 1991, pp. 529)(e.g. a bank closes at 5 pm). In a non-terminating system, such event does not exist.

The importance of these different types of simulation is that in the non-terminating case, a lot of attention must be paid to the problem of the initial transient or the start-up problem (Law et al., 1991, pp. 544) The transient problem means that the system needs some time to get in a steady-state position. [72]

A hospital (the shop level of this model) is clearly a non-terminating system. In this study, the control level (i.e. the HSRP) is also modelled as a non-terminating system. One of the underlying assumptions of HSRP is that it is a system with a rolling planning horizon which does not have a clearly identifiable end. The analysis of output data from steady state simulations present two major difficulties (Thesen et al., 1992): (1) the problem of initial bias and (2) the assumption of independence.

The problem of initial bias in steady state simulations is that near the beginning of the simulation, the observations may not be representative of steady state behaviour (Law et al., pp. 545). When we start our hospital simulation model in an empty state, this is clearly not representative for hospital operations. How long does it take before this initial bias has worked out ? Law et al.(1991, pp. 545) propose several different procedures to deal with this problem. We are going to use a graphical procedure due to Welch. The procedure is the following one (Law et al., 1991, pp. 546):

1. Make n replications of the simulation ($n \geq 5$), each of length m (where m is large). Let Y_{ij} be the *i*th observation from the *j*th replication ($j = 1, 2, ..., n$; $i = 1, 2, ..., m$);

2. Let $Y_i = \dfrac{\sum_{j=1}^{n} Y_{ij}}{n}$

for i= 1, 2, ..., m. Means and variances of the averaged process can be calculated.

[72]In general steady state means that the distribution of a performance measure does not change from one time period to another (Verdini, 1993). For a more detailed definition of steady state see Kleijnen, 1987.

3. Define the moving average $Y_i(w)$ where w is the window and is a positive integer such that $w \leq m/2$.

4. Plot $Y_i(w)$ for i = 1, 2, ..., M-w and choose l to be that value of i beyond which $Y_1(w)$, $Y_2(w)$, ... appears to have converged.

Once the length of the warm-up period has been determined, several approaches are available to estimate performance measures (See Law et al., 1991, pp. 551-564). Fundamentally, there is a distinction between the method of independent replications (with each time a warm-up effect to reduce initial bias) and the method of one long run (Thesen et al., 1992, p.176). The disadvantage of the former method is that a tremendous amount of data is discarded. A way to avoid this discarding of data is to start up the system once and to estimate performance measures during one long run. Here another problem is emerging: the problem of autocorrelation (Kleijnen, 1987, p.58). Autocorrelation or serial correlation means that successive observations are not statistically independent (Thesen et al., 1992, p.181). When a client has to wait for a long time in a queue, the next client will also have a long waiting time. According to Law et al (1991, p.284), simulation output data are always serially correlated. One method to deal with autocorrelation is to divide the (long) simulation run in n batches of length k and to calculate a mean for each batch (Law et al., 1991, p.554). If the batch size or lag k is large enough, it can be shown that the means of two sequential batches are approximately uncorrelated. [73] An important element is then the choice of the batch size, k, so that we obtain uncorrelated batch means. A useful instrument in determining the relationship between the value of the lag k and the autocorrelations is the partial autocorrelation function. In an autocorrelation function, we plot the autocorrelations at lags 0, 1, 2.......,100 against the value of the lag (Box et al., 1978, p.587). If it is true that the statistical dependence of one observation on another is a function of their distance (lag) only, the series of observations is said to be stationary. In this case, beyond the correlation at low lags, the correlation pattern seems to die out (Box et al., 1978; pp. 585-587). An autocorrelationcoefficient can be calculated for each lag k, the so-called sample autocorrelation coefficient (Box et al., p. 585). This coefficient is:

$$r_k = \frac{\sum (Y_i - \overline{Y})(Y_{i+k} - \overline{Y})}{\sum (Y_i - \overline{Y})^2} \qquad (4.1)$$

A problem with the autocorrelation function is that the autocorrelation of the elements within a lag has an impact on the function. To clear out this impact, a partial autocorrelation function can

[73] It can be further shown that the positive correlations decrease exponentially with the time between two successive batches and that the autocorrelations increase with the traffic intensity (Kleijnen, 1987, p.58).

be made up. This is an extension of the autocorrelation function where the dependence on the intermediate elements (those within the lag) is removed (Statsoft, pp. 3258-3259).
When it is assumed that the theoretical autocorrelations are all zero (a so-called white noise process), the standard error of the partial correlation coefficient approximates $1/\sqrt{n}$ [74](Box et al., 1978, p.587). This standard error gives an indication of the significance of the partial autocorrelation coefficient. If the autocorrelation coefficient falls more than 2 standard errors away from 0, there is strong evidence of autocorrelation (Thesen et al., 1992, p.324; see also Box et al., 1970, p.66).

In this study, the modelled system has two levels (or subsystems): the shop level and the planning level. At the shop level, hospital operations start with an empty system. This empty state influences the utilisation of the department in the early stage of simulation. Figure 4.13. clearly shows this start-up bias during the first 100 days. Because of the variability of the data, it is difficult to say how long it takes before the initial bias has worked out. In figure 4.14., a 20-point moving average has been applied to the averaged process of 5 independent replications .[75] In other words we have used the procedure due to Welch. Compared with figure 4.13., we observe in a more clearly way the initial warm-up period. The steady-state occupancy seems to be 15 beds. Although the strongest impact of the initial bias has disappeared at day 100, we feel comfortable with a warm-up period of 400 days. Figure 4.14. shows that during the first 350 days the steady-state occupancy has not completely been reached.

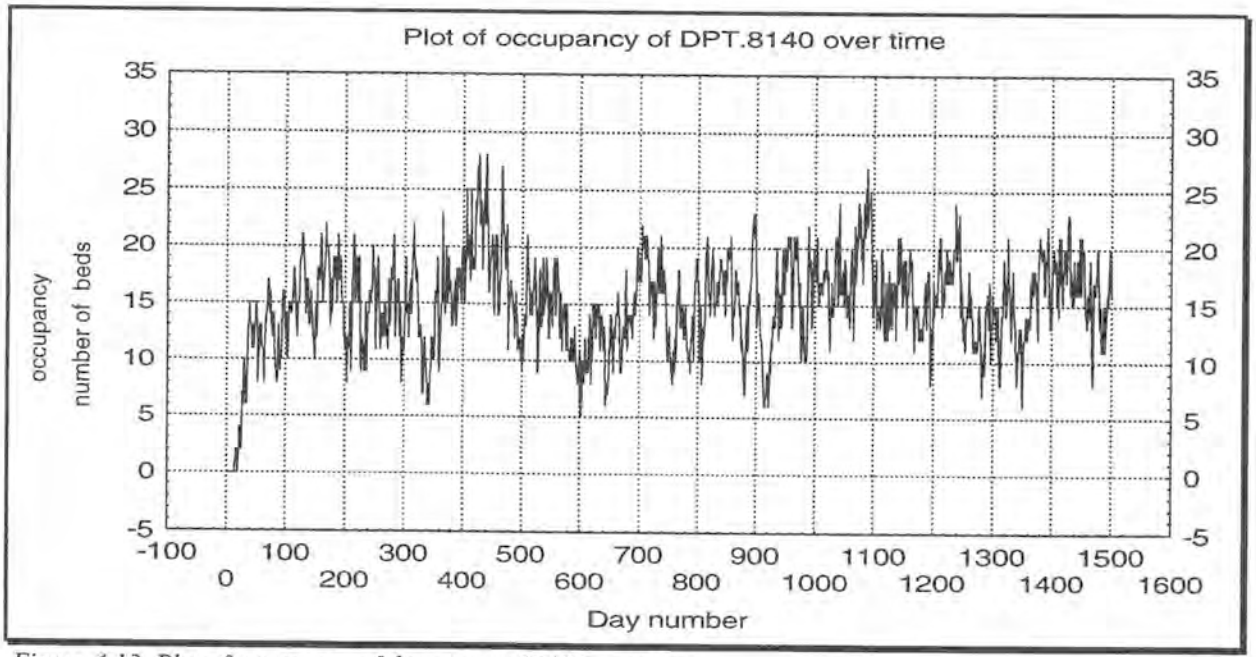

Figure 4.13. Plot of occupancy of department 8140C over time

[74] n = number of observations

[75]. The configuration used in this case is the basic model with no sources of uncertainty, no dynamic order due date maintenance, no safety lead time, a planning frequency of 1 day and capacity limits. In each run, data for 1500 days have been collected.

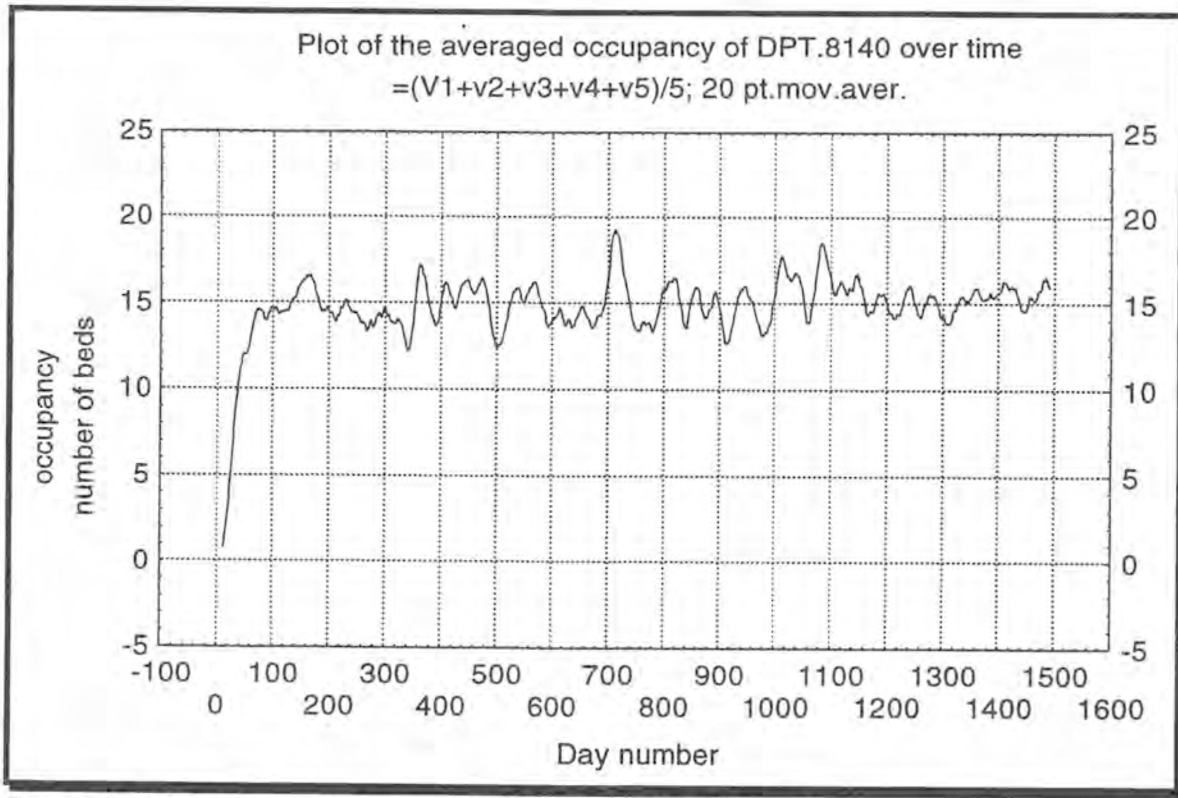

Figure 4.14. Plot of the averaged occupancy of department 8140C over time

A special feature built into the model is that the HSRP system (planning level) works with data collected in the shop level. For instance the standard lead times used in the MRP explosion are based on the average actual lead times (length of stay) observed during some period of time in the real hospital system. This guarantees that the lead times used are in agreement with the system characteristics. We use a data collection period of 200 days. This means that the planning level can only start after 400 days warm-up of the shop-level and after 200 days needed to collect data for the planning level. After the data are collected, the planning level can be warmed up. Figures 4.15. and 4.16. show a plot of the 20 point moving average of the technical performance measures (MPDRX and MPDBED) where each observation is the average of 5 independent runs with a length of 800 days. There is a very strong warm-up effect of approximately 50 days. We have used a warm-up period of 100 days.

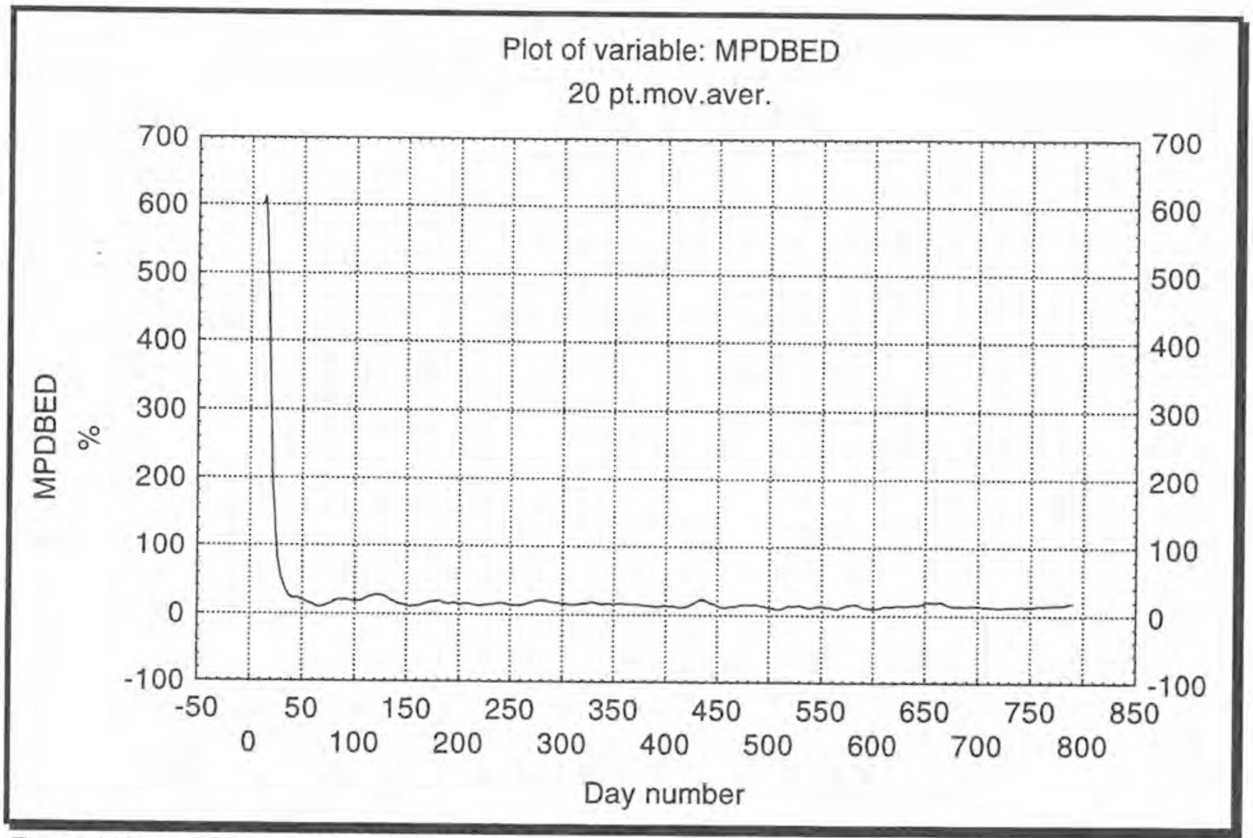

Figure 4.15. Plot of the variable MPDBED over time: 20 point moving average

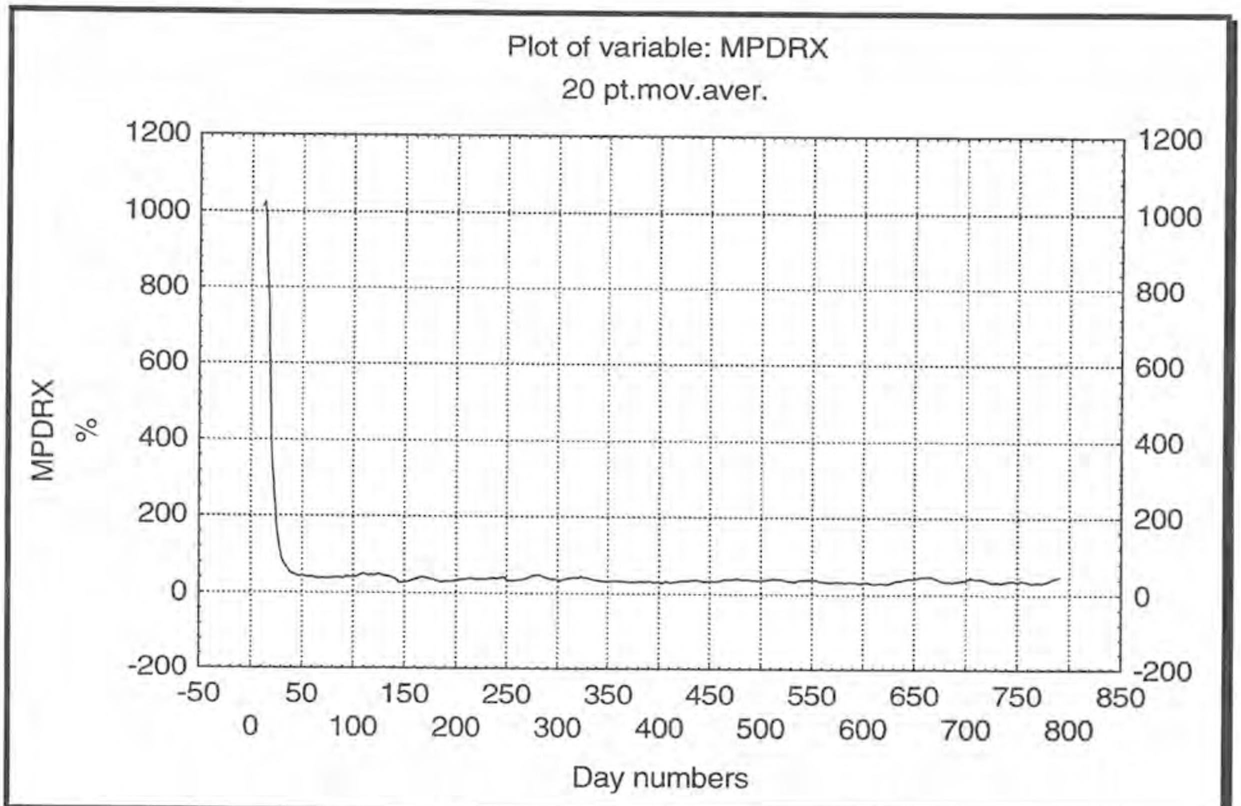

Figure 4.16. Plot of the variable MPDRX over time: 20 point moving average

Because of the long warm-up period (400 days + 200 days + 100 days), the method of the batch means is unavoidable. The main problem with the method of the batch means is autocorrelation.

Autocorrelation in this study is most prevalent when the ICU capacity is finite. We will use a configuration with these characteristics in order to find the batch size. We first obtained 5 independent runs during which HSRP runs for 800 days. Each run results in 800 observations of the MPDRX and MPDBED performance measures. We average the observations for the same day in the different runs. We obtain a plot of the partial autocorrelation coefficients against the lag k for both performance measures (figure 4.17. and figure 4.18.). The correlation pattern clearly dies out in both cases. This means that a steady-state can be reached. At a lag of 100, the partial autocorrelation coefficient is 0.006, which is clearly less than 2 times the standard error (0.0354[76]). Remark that from lag k = 20 no significant results are obtained any more. As long as the lag is greater than 20, we will not have any problems with autocorrelation.

In this study, elements other than autocorrelation influence the batch size. We should like to have the batch size as a multiple of the planning horizon. In the case of a planning periodicity of 7 days, we would like several MRP-explosions to occur during one batch. That's why we have chosen a batch size or lag of 140 days.

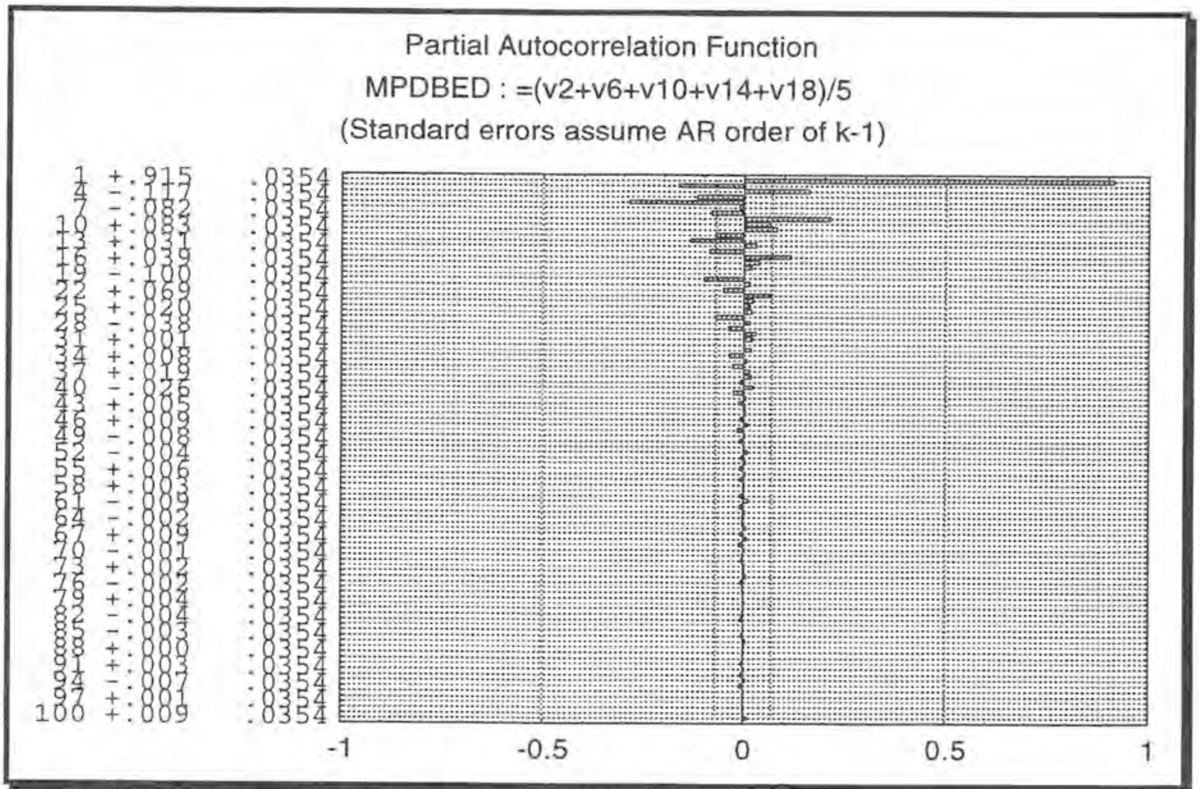

Figure 4.18. Partial autocorrelation function for MPDBED

[76] O.0354 = $1/\sqrt{800}$

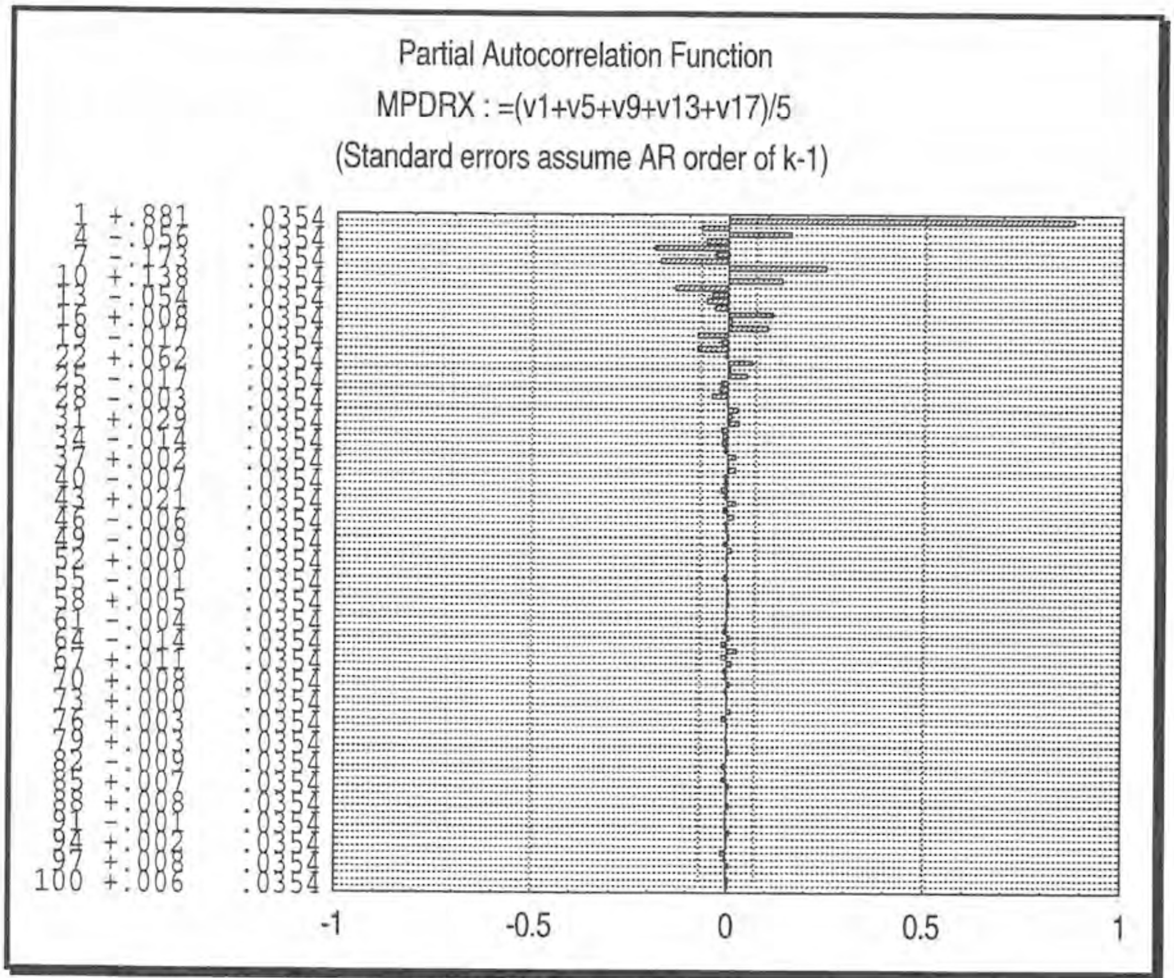

Figure 4.17. Partial correlation function for MPDRX

5. THE ANALYSIS OF THE SIMULATION RESULTS

An important question in the analysis of the simulation results in an experimental design is whether the main and interaction effects are significant or not. Several alternative procedures are proposed and discussed in the next general section. In the second section the significant main and interaction effects in this study are presented.

5.1. Methods for evaluating main and interaction effects

The most common method to test the significance of a particular effect in a factorial design where each factor has two levels is to replicate the whole design n times and obtain n independent values of each effect and to use an approximate 100(1-α)% confidence interval for the expected effects using the t-distribution with n-1 degrees of freedom (see Law et al., 1991, p.664). If the X_i's are normal random variables, the random variable $t_n = \left[X(n)-\mu\right] / \sqrt{s^2(n)/n}$ has a t-distribution with n-1 degrees of freedom. An exact 100(1-α) percent confidence interval for μ is given by (Law et al., 1991, p.288):

$$X(n) \pm t_{n-1,1-\alpha/2}\sqrt{s^2(n)/n} \qquad (5.1.)$$

If the confidence interval for a particular effect does not contain zero, we conclude that this effect is real; otherwise we have no statistical evidence that it is actually present. The disadvantage of this method is that when several effects are simultaneously tested, the Bonferroni inequality must be applied in order to ensure that all statements based on that run are valid (Kleijnen, 1987, p.41). The Bonferroni inequality implies that the individual confidence levels increase. In the case of many different effects, a very high confidence level (or low significance level) implies that the precision of the estimates is very low.

Another method is the so-called method of pooled variances. To test the significance of the effects, the whole design must be replicated n times so that n independent values of each effect can be obtained (Box et al., 1978, p.319). An important assumption is that the replicates of the runs are independent. Another assumption is that the variability of the data does not depend on the levels of the factors (i.e. that all set of conditions in the experiment produce equally variable data).(Thesen et al., 1992, p.238). If a total of N runs is made, the variance of each effect (assuming independent errors) is given by (Box et al., 1978, p.320):

$$\text{variance (effect)} = \frac{4\,\sigma^2}{N} \qquad (5.2.)$$

with N = total number of replications

σ^2 = average of estimated variances

If g sets of experimental conditions are replicated and the n_i replicate runs made at the *i*th set yield an estimate s_i^2 of σ^2 having $v_i = n_i - 1$ degrees of freedom, then s^2 is the pooled estimate of run variance and is a substitute for σ^2 in the above formula. s^2 is then (Box et al., 1978, p.319):

$$s^2 = \frac{v_1 s_1^2 + v_2 s_2^2 + ... + v_g s_g^2}{v_1 + v_2 + ...+ v_g} \quad (5.3.)$$

with $v_1 + v_2 + ...+ v_g$ degrees of freedom.

By taking the square root of variance (effect), we obtain the standard error which can be used for analysis of the experiments. By comparing the estimates (of the effects) with their standard errors in relation to a reference t distribution (with the appropriate number of degrees of freedom and with a scale factor equal to the standard error) (Box et al., 1978, p.317), it can be found which effects are generated by noise and which effects require further interpretation. The disadvantage of this method is the assumption of equal variances whatever the levels of the factors.

Another method tries to find out whether the responses used in the calculation of the main and interaction effects are significantly different or not. Such a test can be obtained by using one-way analysis of variance (to the extent that the assumptions underlying ANOVA are met). One gets an indication of the question whether the different levels of the factors play a significant role in the determination of the dependent variable (Ho et al., 1993). In this case the responses used in the calculation of a particular effect are considered as mean responses of alternative treatments (with several replicates of each treatment). Differences among the means are tested by using two estimators of the variance: the within level error and the between level error. We reject the null hypothesis that the factor has no effect at all if the observed F value exceeds the upper α level of the F variable with a specific degree of freedom.

To perform any of the previous procedures, three assumptions must be met

(1) Independence
(2) normality
(3) equal variances

(1) The independence assumption

In simulation, it is a common practice to use common random numbers (CRN) for the alternative treatment combinations (see Law et al., 1991; Thesen et al., 1992). The method of common random numbers induces positive correlation between the alternative treatment combinations. In other words, when common random numbers are used to generate μ_1 and μ_2, positive correlation is induced between X_{1j} and X_{2j}.[77] This means that the covariance of X_{1j} and X_{2j} is positive and that the variance of the difference between X_{1j} and X_{2j} is reduced. However the use of common random numbers in a simulation experiment is not straightforward. If CRN works and it induces the desired positive correlation between the responses of the alternative configurations, certain covariances enter the expression for the variance of an effect with the wrong sign. The variance could thus increase or decrease depending on the relative magnitudes of the covariances and on which effect is involved (Law et al., 1991, p.664). Remark that inducing positive correlation between treatment populations prohibits the use of any of the analysis methods described before because they all assume that the data points within a data set and between the data sets are independent (Thesen et al., 1992).

(2) The normality assumption

In simulation, this assumption is reasonable because each observation is an average of a large number of individual data points (Thesen et al., 1992, pp. 226). For instance the average length of stay is calculated based on the individual length of stay of approximately 180 patients. Although the individual observations do not have a normal distribution, the central limit theorem gives us enough confidence to accept the assumption of normality. Furthermore some of the procedures such as ANOVA seems to be remarkably robust to deviations from normality (Tabachnick et al., 1983, p.77).

(3) The assumption of equal variances

This assumption of homogeneity of variance across all groups can be somewhat more problematic in simulation applications (Thesen et al., 1992, p.226). Different tests are available for testing this assumption (for a simple test see e.g. Brown and Melamed, 1993, p.95). Again ANOVA is quite robust against violations of this assumption certainly in the case that all groups have an equal size [78](Tabachnick et al., 1983, p.77). Nonetheless, one special case must be very carefully monitored (Statsoft, 1994, pp. 1553). This is the case when the group means are correlated with their variances across cells of the design. In this case, the correlation indicates that the high mean (with high variance) is quite unreliable. A simple plot of the size of the

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[77]For i= 1, 2 let X_{i1}, X_{i2},...., X_{in} be a sample of n_i IID observations from system i, and let $\mu_i = E(X_{ij})$ be the expected response of interest (Law et al., 1991, p.587)

[78] In this study, each group (treatment) has a size of 5 observations.

residuals with the expected value of the response can help to detect this problem (Box et al., 1978, pp. 183).[79]

When assumptions (1) and (3) are not met, it is still possible to use the paired-t confidence interval to analyse the results. In a paired-t confidence interval (or a t-test for dependent samples), we pair X_{1j} with X_{2j} to define $Z_j = X_{1j} - X_{2j}$ (i.e. the *j*th observation of system 1 and 2). An important advantage of the paired-t confidence interval is that we do not have to assume that X_{1j} and X_{2j} are independent or that their variances must be equal. This means that we can use common random numbers (CRN) to allow for positive correlation between X_{1j} and X_{2j}, and thus to smaller confidence intervals (Law et al., 1991, p.587). In fact, by differencing X_{1j} and X_{2j}, we reduce the two-systems problem to one. An approximate $100(1-\alpha)\%$ confidence interval using the t-distribution as previously explained in this section can be applied. In the case of more than two systems, the paired-t confidence interval can still be used but the Bonferroni inequality must be applied because we will be making several confidence-intervals simultaneously (Law et al., pp. 592).

Non-parametric approaches (such as the Wilcoxon matched pairs test) can also be applied when one or more of the assumptions are not met. A Wilcoxon Matched Pair test is used when for instance two samples are related (by means of the specific configuration) and the data are not normally distributed.

In interpreting effects, it is important to note that main effects can only be interpreted individually if there is no evidence that the variable interacts with other variables. If there is evidence of one or more interaction effects, the interacting variables should be considered jointly. One way to interpret an interaction effect between two variables is to make a two-way table by averaging one variable over the levels of the other variable.(Box et al., 1978, p.318).

[79] A residual is the difference between an observation and the groups mean.

5.2. Discussion of the results

5.2.1. The technical performance of HSRP

In this part we only discuss the technical performance of HSRP. The main focus in technical performance measurement is the relationship between the resource requirements as estimated by the HSRP system and the actual resource requirements. Actual resource requirements are not influenced by management decisions which could be made based on the output of HSRP. The deviation of the scheduled discharge date from the actual discharge date is another aspect of technical performance measurement.

Tables 5.1., 5.2., 5.3. and 5.4. show the simulation results for four technical performance measures. Each statistic is the average (respectively the standard deviation) of 5 replications of each 140 days of simulated hospital activity after steady-state was reached. Thus 640 observations (128 configurations * 5 replications) are collected from the simulation model.

The interpretation of table 5.1. is as follows. The '9.68' in the first cell of this table means that the percentage deviation in actual bed requirements from estimated bed requirements (the MPDBED) is in average 9.68%. The average is based on the collection of 5 (independent) observations from one alternative treatment. In this particular case, the treatment is a hospital environment with no sources of uncertainty (i.e. no emergencies, no classification errors, low lead-time uncertainty) and no strategies used to deal with uncertainty (a low planning frequency, no safety lead-time, no dynamic order due date maintenance) and without capacity limits. Further observation of this table learns that there is a range of percentage deviations going from 9.55% to 27.06%. In the former case, this means that if in average the requirements of 100 beds are scheduled, the actual requirements is in average 90 or 110 beds. In the latter case, the actual requirements ranges (in average) from 73 to 127 beds. The standard deviations of the observations within each treatment group are listed in brackets.

Table 5.1. Results for MPDBED (*)

Dynamic	*order due*	*date*		*No*	*No*	*No*	*No*	*Yes*	*Yes*	*Yes*	*Yes*
Capacity	*limits*			*No*	*No*	*Yes*	*Yes*	*No*	*No*	*Yes*	*Yes*
Lead-time	*uncertainty*			*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
Safety-leadtime	Emergency	Classification error	frequency								
No	No	No	Low	9.68 (0.95)	12.33 (1.39)	11.29 (2.27)	16.39 (4.25)	9.65 (0.55)	9.55 (0.50)	10.38 (0.90)	12.24 (2.12)
No	No	No	High	12.10 (4.48)	11.36 (2.12)	11.58 (1.99)	12.83 (2.73)	13.47 (1.43)	14.49 (1.42)	15.66 (5.29)	14.37 (2.15)
No	No	Yes	Low	10.04 (2.17)	11.12 (1.72)	13.79 (2.46)	14.20 (2.06)	9.85 (1.82)	9.54 (0.73)	9.85 (1.00)	12.51 (2.51)
No	No	Yes	high	11.71 (1.83)	11.40 (1.57)	12.09 (2.51)	11.27 (1.31)	12.43 (1.08)	11.55 (1.28)	15.36 (4.02)	17.18 (2.15)
No	Yes	No	Low	14.08 (1.93)	11.85 (1.08)	12.97 (3.19)	15.12 (5.93)	13.79 (1.66)	12.98 (1.84)	12.52 (1.55)	12.79 (2.64)
No	Yes	No	High	10.06 (1.00)	11.22 (2.02)	13.97 (0.92)	13.17 (2.97)	10.26 (1.14)	14.21 (1.86)	12.03 (1.51)	17.94 (4.78)
No	Yes	Yes	Low	12.36 (1.30)	17.47 (3.82)	13.82 (1.93)	13.67 (2.44)	12.53 (1.48)	13.21 (2.01)	13.80 (4.85)	13.75 (2.83)
No	Yes	Yes	High	10.68 (2.29)	10.42 (1.67)	11.36 (1.39)	11.62 (1.48)	10.11 (1.60)	10.92 (1.69)	14.78 (4.54)	12.38 (1.18)
Yes	No	No	Low	11.11 (1.99)	9.59 (1.16)	18.47 (2.02)	21.50 (3.39)	10.35 (1.34)	13.53 (1.75)	15.22 (3.66)	21.05 (1.99)
Yes	No	No	High	12.36 (2.27)	12.34 (1.95)	11.94 (1.11)	14.08 (2.03)	15.64 (1.77)	11.14 (2.14)	27.06 (3.64)	22.30 (3.76)
Yes	No	Yes	Low	15.24 (1.73)	11.64 (0.75)	14.77 (2.84)	20.43 (3.50)	12.33 (1.02)	10.80 (1.60)	17.06 (2.49)	17.77 (1.14)
Yes	No	Yes	High	15.09 (1.45)	13.40 (3.05)	14.51 (2.12)	21.31 (2.13)	17.62 (0.75)	21.38 (1.43)	17.24 (2.17)	16.86 (3.89)
Yes	Yes	No	Low	10.88 (1.69)	13.94 (1.68)	15.24 (1.87)	16.79 (1.32)	10.89 (1.27)	10.36 (0.92)	16.27 (2.14)	16.06 (1.83)
Yes	Yes	No	High	11.21 (1.42)	11.47 (1.46)	13.15 (2.23)	19.99 (1.08)	21.13 (1.96)	23.54 (2.81)	22.83 (4.04)	17.31 (3.22)
Yes	Yes	Yes	Low	13.20 (1.97)	17.34 (4.85)	15.24 (1.91)	18.06 (1.56)	10.71 (2.12)	12.70 (1.37)	13.97 (0.53)	13.29 (2.82)
Yes	Yes	Yes	high	20.68 (2.46)	15.25 (2.24)	15.27 (0.67)	22.38 (2.16)	21.24 (0.85)	16.65 (3.33)	25.41 (6.66)	17.53 (2.57)

(*) the first statistic is the average response for a treatment based on 5 observations
the second statistic (within brackets) is the standard deviation of these 5 observations within a treatment.

Table 5.2. Results for MPDRX (*)

dynamic	*order due*	*date*		*No*	*No*	*No*	*No*	*Yes*	*Yes*	*Yes*	*Yes*
capacity	*limits*			*No*	*No*	*Yes*	*Yes*	*No*	*No*	*Yes*	*Yes*
lead-time	*uncertainty*			*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
Safetyldt	Emergency	Classification error	frequency								
No	No	No	Low	27.59 (2.29)	34.11 (2.21)	33.63 (4.36)	45.88 (8.86)	35.58 (2.84)	32.21 (4.45)	33.36 (2.34)	39.28 (5.59)
No	No	No	High	31.31 (2.55)	33.89 (2.69)	34.82 (4.55)	29.66 (4.00)	21.49 (1.04)	21.77 (2.72)	26.69 (3.72)	20.24 (0.66)
No	No	Yes	Low	35.03 (3.24)	35.61 (2.57)	38.36 (3.88)	30.71 (1.79)	31.93 (3.09)	31.62 (2.95)	44.53 (1.55)	57.99 (5.33)
No	No	Yes	High	35.70 (3.08)	31.40 (2.20)	28.70 (4.11)	31.29 (1.03)	23.71 (1.44)	20.84 (2.96)	22.95 (1.73)	21.97 (2.17)
No	Yes	No	Low	38.05 (6.12)	36.96 (4.38)	40.55 (4.14)	38.00 (6.31)	41.15 (1.41)	39.87 (2.91)	37.52 (6.20)	35.36 (4.12)
No	Yes	No	High	30.75 (1.93)	31.26 (3.92)	31.63 (2.93)	32.27 (3.71)	22.09 (2.21)	21.41 (1.13)	24.70 (1.24)	22.34 (2.48)
No	Yes	Yes	Low	36.93 ((1.58)	40.27 (5.02)	33.85 (1.57)	40.36 (3.01)	45.03 (5.19)	45.46 (4.82)	52.95 (9.58)	53.28 (11.70)
No	Yes	Yes	High	33.43 (1.38)	35.36 (2.05)	32.88 (1.82)	35.45 (2.86)	23.83 (1.23)	21.07 (2.32)	24.74 (1.26)	21.21 (1.29)
Yes	No	No	Low	25.86 (1.77)	23.82 (1.39)	20.26 (2.19)	25.14 (3.20)	29.91 (2.04)	28.81 (2.23)	33.14 (5.34)	22.37 (1.49)
Yes	No	No	high	25.62 (1.43)	25.40 (1.71)	28.68 (2.86)	29.63 (2.00)	20.08 (2.08)	23.65 (2.10)	20.60 (0.71)	20.87 (1.66)
Yes	No	Yes	Low	24.30 (2.69)	24.67 (1.70)	25.64 (1.68)	25.20 (2.75)	27.16 (3.00)	27.59 (1.66)	26.25 (1.09)	37.71 (2.77)
Yes	No	Yes	High	22.88 (3.00)	22.85 (1.95)	23.69 (1.60)	23.40 (4.82)	20.09 (1.37)	19.53 (2.26)	20.09 (2.77)	21.97 (1.23)
Yes	Yes	No	Low	24.76 (2.38)	24.28 (2.59)	24.50 (1.52)	27.50 (2.67)	28.79 (1.52)	31.72 (2.58)	26.38 (2.56)	32.76 (5.03)
Yes	Yes	No	High	27.45 (1.57)	27.73 (2.00)	26.95 (2.67)	25.94 (2.55)	19.87 (2.35)	20.54 (2.05)	20.83 (0.27)	21.40 (2.19)
Yes	Yes	Yes	Low	27.50 (1.53)	24.31 (2.10)	23.73 (1.48)	26.57 (1.38)	34.53 (3.90)	37.26 (1.80)	34.36 (4.53)	31.99 (4.05)
Yes	Yes	Yes	High	22.32 (4.00)	23.76 (2.93)	27.08 (3.49)	25.47 (2.54)	19.65 (0.56)	19.02 (1.58)	22.14 (3.56)	21.47 (2.20)

(*) the first statistic is the average response for a treatment based on 5 observations
the second statistic (within brackets) is the standard deviation of these 5 observations within a treatment.

Table 5.3. Results for MADHIST (*)

Dynamic	order due	date		No	No	No	No	Yes	Yes	Yes	Yes
Capacity	limits			No	No	Yes	Yes	No	No	Yes	Yes
Lead-time	Uncertainty			Low	High	Low	High	Low	High	Low	High
Safetyldt	Emergency	Classification error	frequency								
No	No	No	Low	5.19 (0.59)	4.93 (0.40)	5.05 (0.49)	5.71 (0.50)	5.53 (0.17)	4.97 (0.33)	.5.12 (0.39)	5.38 (0.63)
No	No	No	High	5.11 (0.77)	4.84 (0.51)	5.03 (0.75)	5.47 (0.34)	4.97 (0.38)	5.25 (0.42)	5.47 (0.36)	5.00 (0.19)
No	No	Yes	Low	5.17 (0.63)	5.33 (0.32)	5.90 (0.36)	5.84 (0.14)	5.15 (0.58)	5.45 (0.36)	5.84 (0.48)	6.17 (0.50)
No	No	Yes	High	5.57 (0.36)	5.52 (0.56)	5.68 (0.45)	5.51 (0.21)	5.31 (0.35)	5.43 (0.45)	5.48 (0.28)	5.31 (0.37)
No	Yes	No	Low	5.09 (0.41)	5.05 (0.44)	4.98 (0.47)	5.48 (0.54)	4.72 (0.22)	4.99 (0.46)	5.33 (0.42)	5.20 (0.39)
No	Yes	No	High	5.15 (0.34)	5.01 (0.35)	5.54 (0.45)	5.15 (0.65)	4.67 (0.50)	4.97 (0.19)	5.42 (0.20)	5.25 (0.23)
No	Yes	Yes	Low	5.51 (0.46)	5.18 (0.35)	6.16 (0.44)	5.54 (0.50)	5.03 (0.32)	5.62 (0.28)	6.52 (0.49)	5.99 (0.34)
No	Yes	Yes	High	5.08 (0.46)	5.16 (0.49)	5.91 (0.31)	5.76 (0.67)	5.82 (0.49)	5.49 (0.44)	5.49 (0.35)	5.43 (0.27)
Yes	No	No	Low	5.77 (0.33)	5.60 (0.45)	6.57 (0.27)	7.11 (0.48)	6.10 (0.63)	5.75 (0.61)	7.07 (0.69)	7.11 (0.56)
Yes	No	No	High	5.90 (0.50)	5.71 (0.35)	5.95 (0.80)	5.74 (0.56)	5.62 (0.09)	6.14 (0.33)	7.97 (0.24)	6.38 (0.55)
Yes	No	Yes	Low	6.33 (0.20)	6.02 (0.43)	6.00 (0.57)	7.33 (0.42)	6.81 (0.43)	5.99 (0.38)	6.64 (0.28)	7.52 (0.28)
Yes	No	Yes	High	6.52 (0.74)	6.28 (0.44)	6.12 (0.42)	6.62 (0.37)	6.42 (0.35)	6.44 (0.38)	7.34 (0.64)	6.54 (0.54)
Yes	Yes	No	Low	5.61 (0.22)	6.25 (0.50)	5.94 (0.59)	6.35 (0.78)	6.96 (0.21)	5.74 (0.26)	6.02 (0.39)	5.86 (0.41)
Yes	Yes	No	High	5.40 (0.52)	5.72 (0.38)	6.02 (0.93)	6.07 (0.25)	6.39 (0.41)	5.97 (0.15)	6.22 (0.40)	6.12 (0.27)
Yes	Yes	Yes	Low	5.89 (0.15)	7.31 (0.15)	6.57 (0.34)	6.45 (0.55)	5.91 (0.37)	6.04 (0.23)	6.30 (0.43)	6.83 (0.52)
Yes	Yes	Yes	High	7.37 (0.34)	6.66 (0.18)	6.01 (0.33)	7.13 (0.71)	6.69 (0.31)	5.66 (0.51)	6.86 (0.71)	7.05 (0.63)

(*) the first statistic is the average response for a treatment based on 5 observations
the second statistic (within brackets) is the standard deviation of these 5 observations within a treatment.

Table 5.4. Results for MADCUR (*)

dynamic	*order due*	*date*		*No*	*No*	*No*	*No*	*Yes*	*Yes*	*Yes*	*Yes*
capacity	*limits*			*No*	*No*	*Yes*	*Yes*	*No*	*No*	*Yes*	*Yes*
lead-time	*uncertainty*			*Low*	*High*	*Low*	*High*	*Low*	*High*	*Low*	*High*
Safetyldt	Emergency	Classifica-tion error	frequen-cy								
No	No	No	Low	5.19 (0.59)	4.93 (0.40)	5.05 (0.49)	5.71 (0.50)	4.57 (0.23)	3.83 (0.09)	3.94 (0.21)	4.24 (0.60)
No	No	No	High	5.11 (0.77)	4.84 (0.51)	5.03 (0.75)	5.47 (0.34)	3.91 (0.30)	4.33 (0.37)	4.08 (0.51)	3.94 (0.24)
No	No	Yes	Low	5.17 (0.63)	5.33 (0.32)	5.90 (0.36)	5.84 (0.14)	4.00 (0.74)	4.02 (0.52)	4.14 (0.53)	3.93 (0.46)
No	No	Yes	High	5.57 (0.36)	5.52 (0.56)	5.68 (0.45)	5.51 (0.21)	3.93 (0.27)	4.12 (0.46)	4.08 (0.41)	3.95 (0.34)
No	Yes	No	Low	5.09 (0.41)	5.05 (0.44)	4.98 (0.47)	5.48 (0.54)	3.66 (0.12)	3.78 (0.49)	4.19 (0.36)	3.80 (0.40)
No	Yes	No	High	5.15 (0.34)	5.01 (0.35)	5.54 (0.45)	5.15 (0.65)	3.58 (0.27)	3.97 (0.23)	4.12 (0.37)	4.05 (0.19)
No	Yes	Yes	Low	5.51 (0.46)	5.18 (0.35)	6.16 (0.44)	5.54 (0.50)	3.65 (0.35)	4.15 (0.40)	4.24 (0.30)	3.97 (0.26)
No	Yes	Yes	High	5.08 (0.46)	5.16 (0.49)	5.91 (0.31)	5.76 (0.67)	4.40 (0.33)	3.96 (0.38)	3.85 (0.44)	4.08 (0.12)
Yes	No	No	Low	5.77 (0.33)	5.60 (0.45)	6.57 (0.27)	7.11 (0.48)	4.82 (0.68)	4.63 (0.44)	4.58 (0.34)	5.79 (0.28)
Yes	No	No	High	5.90 (0.50)	5.71 (0.35)	5.95 (0.80)	5.74 (0.56)	4.44 (0.29)	4.68 (0.27)	6.35 (0.19)	4.95 (0.36)
Yes	No	Yes	Low	6.33 (0.20)	6.02 (0.43)	6.00 (0.57)	7.33 (0.42)	5.00 (0.39)	4.39 (0.43)	5.10 (0.36)	5.18 (0.38)
Yes	No	Yes	High	6.52 (0.74)	6.28 (0.44)	6.12 (0.42)	6.62 (0.37)	5.06 (0.28)	4.96 (0.24)	4.74 (0.36)	4.61 (0.52)
Yes	Yes	No	Low	5.61 (0.22)	6.25 (0.50)	5.94 (0.59)	6.35 (0.78)	4.54 (0.22)	4.46 (0.43)	4.57 (0.35)	4.57 (0.20)
Yes	Yes	No	High	5.40 (0.52)	5.72 (0.38)	6.02 (0.93)	6.07 (0.25)	5.14 (0.43)	5.14 (0.18)	4.70 (0.27)	4.72 (0.24)
Yes	Yes	Yes	Low	5.89 (0.15)	7.31 (0.15)	6.57 (0.34)	6.45 (0.55)	4.23 (0.44)	4.41 (0.33)	4.59 (0.41)	4.89 (0.27)
Yes	Yes	Yes	High	7.37 (0.34)	6.66 (0.18)	6.01 (0.33)	7.13 (0.71)	5.58 (0.50)	4.56 (0.58)	5.06 (0.53)	5.20 (0.63)

(*) the first statistic is the average response for a treatment based on 5 observations

the second statistic (within brackets) is the standard deviation of these 5 observations within a treatment

Table 5.2. can be interpreted in the same way as table 5.1.. In this table, it concerns the chest X-resources (RX) which are only partially length of stay dependent. When comparing the two tables, it can be concluded that in most cases, the technical performance in predicting resource requirements is better for the bed resources than for the Rx resources[80]. A Wilcoxon Matched-Pairs test confirms this observation. A Wilcoxon Matched-Pairs test is used because of the non-normality of the data. The null hypothesis is that there is no difference between the technical performance for the two kinds of resources. The alternative hypothesis is that the performance in the case of bed resources is better than the performance in the case of Rx resources. Table 5.5. shows the result of this test. When the number of observations is greater than 25, the sampling distribution of T - the test statistic of the Wilcoxon Matched-Pairs test- approximates the normal distribution. In this case, the calculated z-value is much larger than z = 2.33 (which is the standard normal z-value for a one-tailed test at a level of significance α of 0.01).

Table 5.5. Wilcoxon Matched-Pairs test for MPDRX and MPDBED

	valid n	T	z	p-level
MPDRX & MPDBED	640	3193	21.23	0.00

A box and Whisker plot (figure 5.1.) clearly shows the better
performance of bed resources (MPDBED) over chest X-ray resources (MPDRX). Almost 75% of the MPDBED values are smaller than the minimum value of MPDRX.

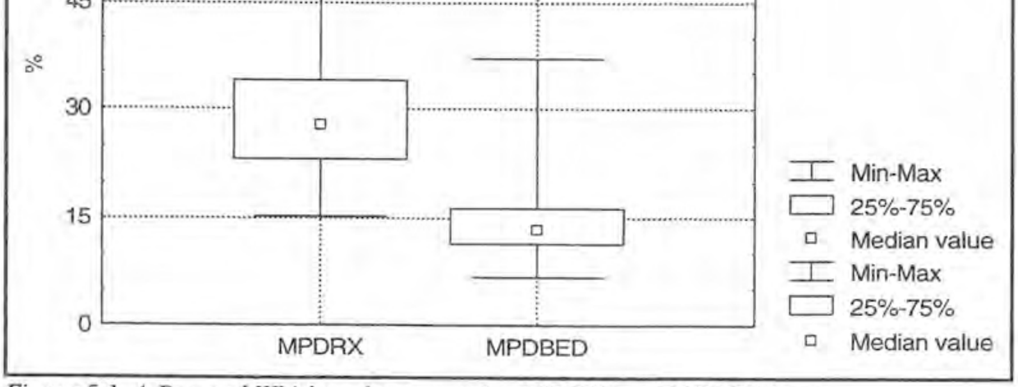

Figure 5.1. A Box and Whisker plot comparing MPDRX and MPDBED

80 Chest X-ray and Rx are interchangeably used.

Tables 5.3 and 5.4 show the results in terms of the mean absolute deviation between the actual discharge and the original (respectively most recently updated) scheduled discharge date (MADHIST and MADCUR). A value of 5.19 in the first cell in table 5.3 means that there is an average deviation of 5 days between the actual discharge date and the originally scheduled discharge date. The interpretation of table 5.4 is the same.
A strategy of updating the discharge date using a dynamic order due date maintenance clearly improves the accuracy of the predictions of the discharge date in all treatments (where this strategy is applied). This can be observed by comparing those columns in tables 5.3 and 5.4 for which the parameter 'dynamic order due date maintenance strategy' is set on 'Yes'. A Wilcoxon Matched Pair test strongly confirms this observation (table 5.6.). The null hypothesis is that there is no difference in the accuracy of the prediction of the discharge date between the two measures (MADHIST and MADCUR). The alternative hypothesis is that the performance in the case of the most recently updated discharge date (MADCUR) is better than the performance in the case of the original scheduled discharge date. The calculated z-value is much larger than $z = 2.33$ (which is the standard normal z-value for a one-tailed test at a level of significance α of 0.01).
Remark that the MADHIST is never better than the MADCUR (the T test statistic is 0). In the subsequent statistical analysis, we do not further consider the mean absolute deviation between the actual discharge date and the original scheduled discharge date (MADHIST).

Table 5.6. Wilcoxon Matched-Pairs test for MADCUR and MADHIST

	valid n	T	z	p-level
MADHIST & MADCUR	320 (*)	0	15.50	0.00

(*) The test is only applied to those treatments with dynamic order due date maintenance.
In the other treatments, there is no difference between MADCUR and MADHIST.

The results in the tables 5.1. to 5.4. are obtained without the use of any variance-reduction techniques (such as common random numbers). By using the method of independent replicates, we may be quite sure that the assumption of independence has been met. [81] In examining normality and equality of variances, some problems have been detected as to the equality of the variances in the case of MPDRX and MPDBED performance measurement. Figures 5.2. and 5.3. show that there is some positive correlation between the means and the variances across

[81]. Of course everything depends on the way the pseudo-random generator of SIMSCRIPT II.5 really simulates the characteristics of uniform and independent distributed observations (Kleijnen et al., 1992, p.20). An important consideration is the length of the so-called cycle or period which indicates when the same stream of number reoccurs. Russel pretends that even after 1.000.000 samples, this period has not been approached (Russel, 1992, p.4-2).

the cells of the design for MPDRX and MPDBED (the correlation coefficients are respectively 0.62 and 0.42). Such correlation does not exist in case of MADCUR (figure 5.4.). These findings can also be observed in tables 5.1, 5.2, and 5.4. Based on these tables, we can conclude that in most cases, the standard deviation is not large enough to create unreliable conclusions when the mean is large.

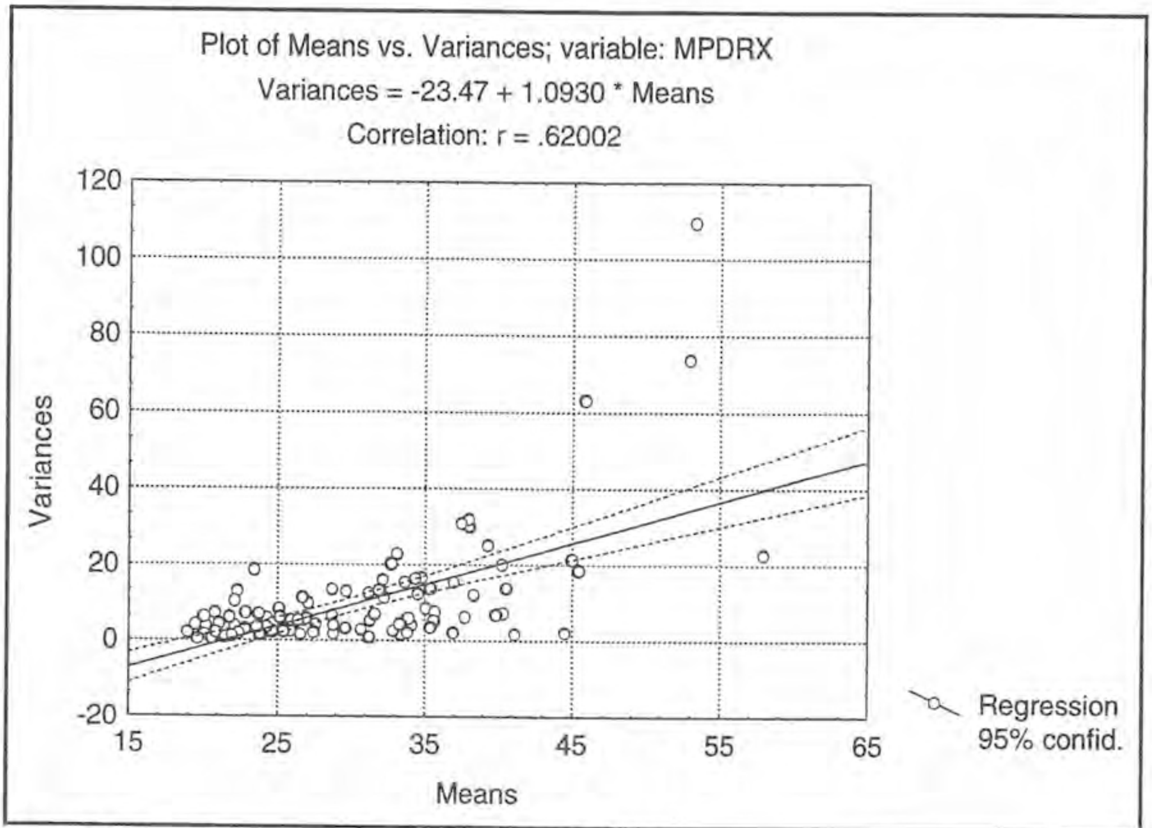

Figure 5.2. Plot of means versus variances; variable MPDRX

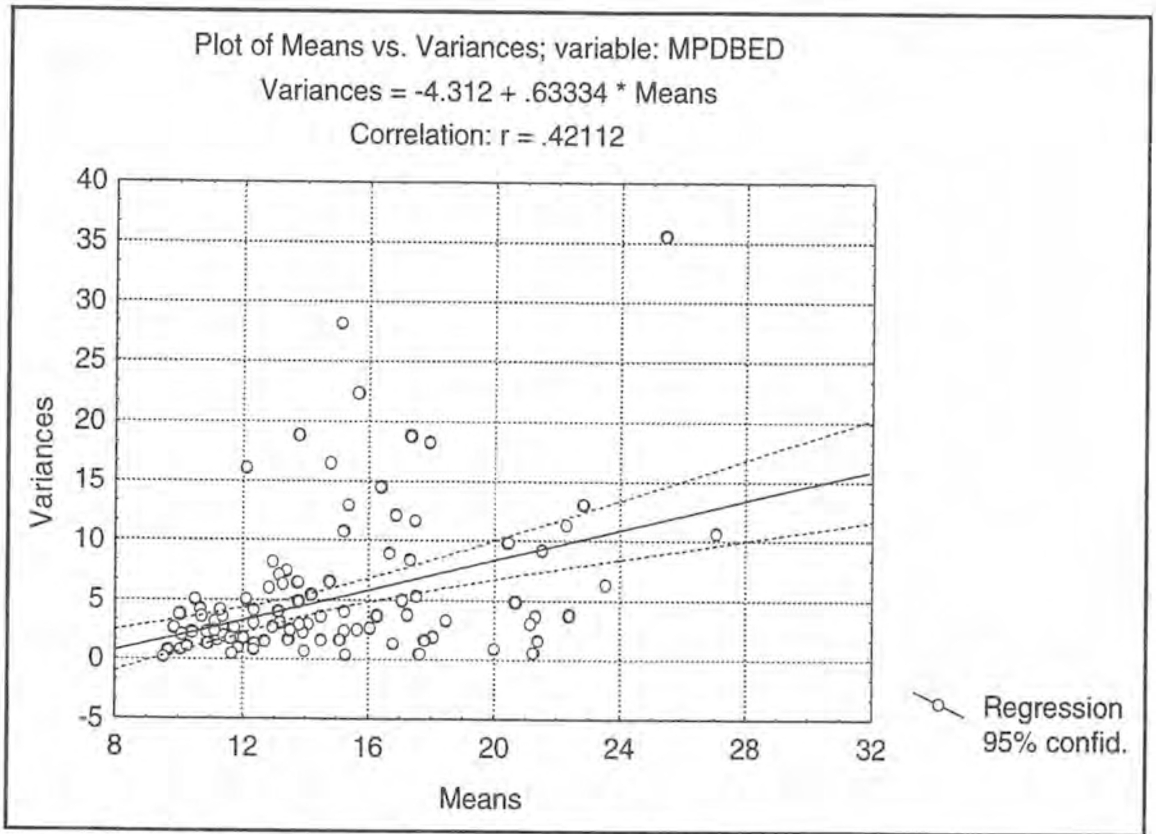

Figure 5.3. Plot of means versus variances, variable MPDBED

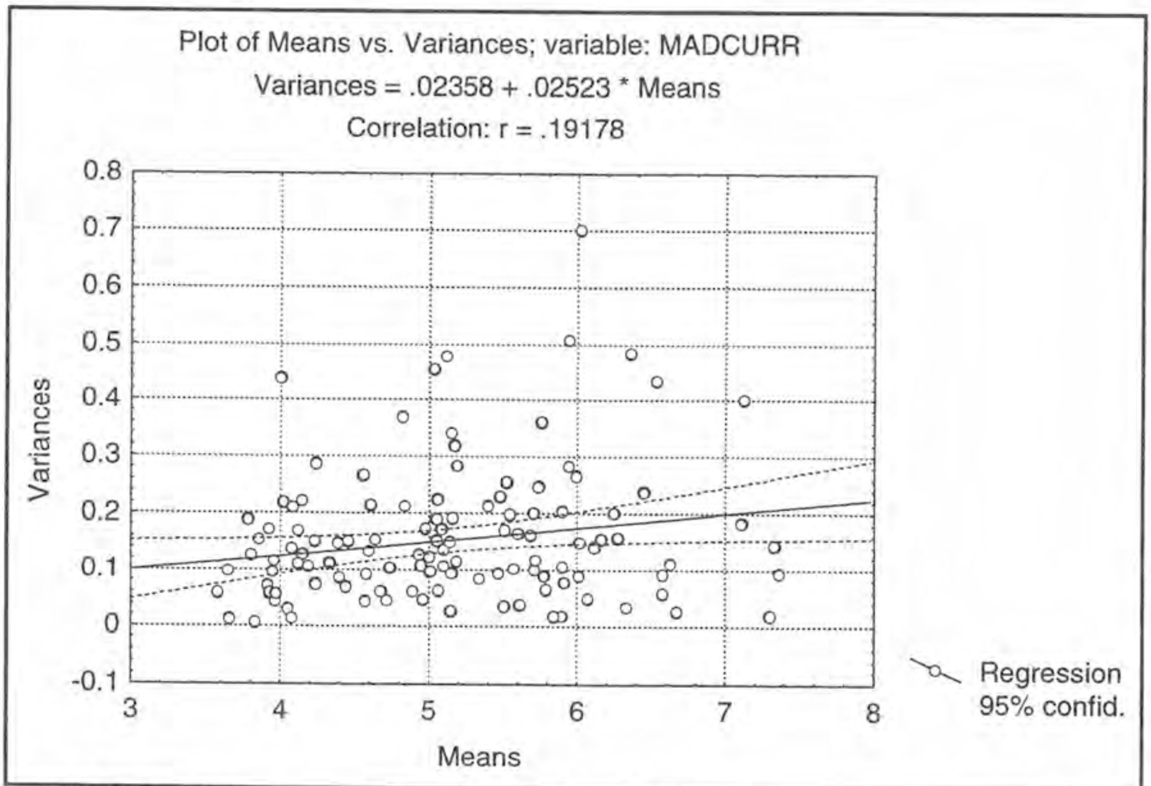

Figure 5.4. Plot of means versus variances; variable MADCUR

The visual observations on the experimental results can be further examined and clarified through statistical analysis. We use ANOVA. Regarding conditions for ANOVA's applicability, the requirement of independent data within a treatment is met by the independent replications. ANOVA is robust to departure from normality and variance-homogeneity, as long as sample sizes are relatively equal (Tabachnick et al., 1983, p.77) [82].

Table 5.7 shows the ANOVA results with the three performance measures MPDRX, MPDBED and MADCUR as dependent variables.[83] The model presented here - we call this the 'limited model'- only contains the main, two-way and three-way interaction effects. The full ANOVA-model (with all interaction effects included) is listed in appendix 10. Table 5.8 further learns that the limited model explains 78%, 58% and 78% of the deviations of treatment averages from the grand average in the case of respectively MPDRX, MPDBED and MADCUR.[84] The full model explains respectively 87%, 74% and 84% of the deviations of treatment averages from the grand average Only in the case of MPDBED, one could argue that the full model remarkably improve the explanatory power of the model. This is the result of some significant 6-way and 7-way interaction effects. Because these higher level interaction effects cannot be explained, we have decided to limit our discussion to the limited model. We are aware that we may introduce some error in the discussion because of the higher level interaction effects. Nonetheless, the high explanatory power of the limited model certainly in the case of MPDRX and MADCUR reassures us that we deal with the most relevant factor effects. [85]

[82] In our study, the sample size for each treatment is 5.
[83] MPDRX = the percentage deviation in actual Rx requirements from estimated Rx requirements; MPDBED = the percentage deviation in actual bed requirements from estimated bed requirements; MADCUR = the mean absolute deviation between the actual discharge date and the most recently updated scheduled discharge date.
[84] The grand average is defined as the sum of all the observations divided by the total number of observations. (Box et al., 1978). The grand average is 29.23% in the case of MPDRX, 14.27% in the case of MPDBED and 5.13 days in the case of MADCUR.
[85] A factor effect is relevant when the change in the performance measure is not only significant, but also large enough to be worthwhile to consider. For instance, an improvement of MPDRX from 31% to 21% is worthwile to consider while an improvement of MPDRX from 31% to 28% does not make a lot of change (although it may be statistically significant).

Table 5.7. ANOVA results: MPDRX, MPDBED and MADCUR as dependent variable: summary of main, two-way and three-way interaction effects.

Source: 1 = Dynamic order due date maintenance strategy
2 = Capacity limits
3.= Lead-time uncertainty
4 = Safety lead time
5 = Emergencies
6 = Classification error
7 = Planning frequency

Bold figures are significant at $p < 0.01$ level

SOURCE	MPDRX F-value	MPDRX P-level	MPDBED F-value	MPDBED P-level	MADCUR F-value	MADCUR P-level
1	12.42	**0.000458**	14.61	**0.000147**	1252.36	**0.000000**
2	18.82	**0.000017**	123.20	**0.000000**	30.61	**0.000000**
3	2.47	0.116259	8.66	**0.003380**	0.71	0.400839
4	589.29	**0.000000**	230.39	**0.000000**	507.07	**0.000000**
5	30.22	**0.000000**	6.41	0.011585	1.89	0.170018
6	12.43	**0.000456**	1.20	0.274510	36.03	**0.000000**
7	627.76	**0.000000**	46.26	**0.000000**	0.54	0.463957
12	4.64	0.031738	0.09	0.758224	4.29	0.038779
13	0.57	0.449828	9.96	**0.001685**	4.49	0.034605
23	1.50	0.221322	4.43	0.035815	3.38	0.066380
14	25.74	**0.000001**	8.22	**0.004295**	0.40	0.525950
24	6.67	0.010069	20.83	**0.000006**	0.06	0.807934
34	0.09	0.762136	0.20	0.658982	2.44	0.118765
15	1.59	0.207154	0.33	0.567622	5.08	0.024516
25	5.80	0.016304	11.26	**0.000845**	2.16	0.141972
35	0.29	0.591622	0.14	0.706069	0.21	0.649858
45	3.92	0.048104	0.27	0.600345	0.00	0.980734
16	25.19	**0.000001**	15.15	**0.000111**	36.52	**0.000000**
26	3.54	0.060360	8.89	**0.002986**	2.77	0.096701
36	0.21	0.646975	1.43	0.232109	0.17	0.682619
46	13.26	**0.000296**	7.06	**0.008115**	0.55	0.458088
56	6.46	0.011317	0.26	0.611692	6.85	**0.009097**
17	385.10	**0.000000**	96.54	**0.000000**	7.67	**0.005782**
27	4.79	0.029048	2.50	0.114121	7.76	**0.005533**
37	8.41	**0.003883**	6.28	0.012492	5.44	0.020035
47	110.62	**0.000000**	34.48	**0.000000**	1.13	0.288952
57	19.79	**0.000010**	0.05	0.820341	6.83	**0.009182**
67	32.07	**0.000000**	0.15	0.700241	1.86	0.173037
123	0.01	0.910961	12.57	**0.000425**	1.77	0.183391
124	7.43	**0.006606**	0.22	0.638532	3.96	0.046982
134	3.09	0.079431	7.76	**0.005526**	6.22	0.012880
234	0.02	0.885788	2.71	0.100250	3.72	0.054156
125	2.96	0.086081	0.38	0.535603	0.09	0.767066
135	0.61	0.435372	1.47	0.225729	0.04	0.843031
235	0.95	0.328969	4.71	0.030388	3.76	0.052966
145	0.07	0.791025	0.56	0.454591	1.13	0.288221
245	2.98	0.085084	4.48	0.034760	11.47	**0.000754**
345	0.59	0.443266	0.46	0.499522	1.94	0.164586
126	23.46	**0.000002**	0.31	0.575722	0.01	0.917935
136	3.51	0.061492	0.68	0.409574	0.13	0.722010
236	2.18	0.140492	0.00	0.937069	0.42	0.515504
146	1.38	0.240386	9.82	**0.001816**	2.33	0.127341

Table 5.7 (continued) ANOVA results: MPDRX, MPDBED and MADCUR as dependent variable: summary of main, two-way and three-way interaction effects.

Source: 1 = Dynamic order due date maintenance strategy
2 = Capacity limits
3.= Lead-time uncertainty
4 = Safety lead time
5 = Emergencies
6 = Classification error
7 = Planning frequency

Bold figures are significant at $p < 0.01$ level

	MPDRX	MPDRX	MPDBED	MPDBED	MADCUR	MADCUR
SOURCE	F-value	P-level	F-value	P-level	F-value	P-level
246	0.03	0.872778	8.81	**0.003116**	6.08	0.013958
346	0.01	0.916568	0.43	0.512159	0.84	0.360661
156	0.85	0.357725	0.88	0.348514	0.14	0.713588
256	0.10	0.752726	0.80	0.370789	1.83	0.177125
356	0.00	0.955606	0.93	0.335324	0.20	0.654499
456	0.29	0.592300	0.34	0.557939	2.05	0.152730
127	1.60	0.207013	1.29	0.256295	0.23	0.633724
137	0.55	0.458822	0.45	0.500383	0.51	0.473832
237	5.63	0.017992	0.09	0.766895	0.74	0.390106
147	8.78	**0.003166**	6.63	0.010283	4.29	0.038779
247	18.44	**0.000021**	12.31	**0.000486**	2.64	0.104684
347	3.62	0.057530	2.16	0.142138	7.15	**0.007716**
157	5.47	0.019729	0.26	0.610364	0.93	0.335874
257	12.72	**0.000391**	6.44	0.011409	1.29	0.256642
357	0.85	0.356087	0.19	0.664676	0.00	0.925605
457	2.15	0.143469	42.98	**0.000000**	3.17	0.075645
167	14.06	**0.000195**	2.48	0.115988	1.62	0.203746
267	5.09	0.024415	0.27	0.605628	3.18	0.075119
367	0.45	0.504017	0.12	0.728937	0.21	0.649858
467	0.01	0.915633	6.08	0.013975	1.78	0.182335
567	0.00	0.923115	1.24	0.266282	0.02	0.888611

Table 5.8. The explanatory power of the limited and the full ANOVA models.[86]

	Sum of squares	%	Sum of squares	%	Sum of squares	%
Limited model	MPDRX	MPDRX	MPDBED	MPDBED	MADCUR	MADCUR
Explained	33744	78%	6814	58%	483	78%
Residual	9329	22%	4902	42%	139	22%
Total	43073	100%	11716	100%	622	100%
Full model						
Explained	37579	87%	8693	74%	524	84%
Residual	5494	13%	3023	26%	98	100%
Total	43073	100%	11716	100%	622	10%

[86] The degrees of freedom of the effect and the error term are respectively 576 and 1.

5.2.1.1. The ANOVA results for the percentage deviation in actual Rx requirements from estimated Rx requirements (MPDRX)

The MPDRX columns in table 5.7. show the ANOVA-results for the limited design with MPDRX as dependent variable. All but one of the main effects are significant at $p < 0.001$ level. Table 5.9. shows the direction and amount of the main effect for each of these factors. A move from (-) to (+) level means the introduction of dynamic order due date maintenance, finite capacity, safety lead-time and higher planning frequency. It also means higher lead-time uncertainty, emergencies and classification error. In general, the direction of the main effects by moving from (-) level to (+) level is expected: a lower % deviation in the case of the strategies introduced to deal with uncertainty (dynamic order due date maintenance, safety lead-time, higher planning frequency and slack capacity[87]); a higher % deviation with the different sources of uncertainty (lead-time uncertainty, emergencies and classification error). It can be observed that there are also many interaction effects which must be discussed together with the main effects.

Table 5.9. Main effects for MPDRX

MAIN EFFECTS	(-) level (in %)	(+) level (in %)
Dynamic order due date maintenance	29.88	28.76
Slack capacity	28.63	30.01
Lead-time uncertainty	29.07	29.57
Safety lead-time	33.18	25.46
Emergencies	28.45	30.20
Classification error	28.76	29.88
Planning frequency	33.31	25.34

A first remark is that there is a very strong significance of the main effect of the factors planning frequency and safety lead time, and of the two-way interaction between planning frequency and dynamic order due date maintenance (see table 5.7.). The latter effect learns that a combination of a daily planning periodicity and dynamic order due date maintenance leads to higher accuracy in the prediction of the requirements for chest x-ray resources. Figure 5.5. shows that the average performance increases from a MPDRX of 31% in the case of low planning frequency and no due date maintenance to a MPDRX of 21% in the case of high planning frequency and dynamic order due date maintenance.

Based on figure 5.5. it becomes clear that a strategy of dynamic order due date maintenance is not meaningful when the planning periodicity is one week (or when the planning frequency is low). In the case of low planning frequency, the introduction of dynamic order due date maintenance decreases MPDRX from 31% to 36%. To be useful a daily planning periodicity

[87] In the case of slack capacity, we have to move from (+) level to (-) level to see the positive effect.

(or high planning frequency) must accompany a strategy of dynamic order due date maintenance. This modifies hypothesis 3 which states that a strategy of dynamic order due date maintenance always increases the technical performance of HSRP (although we specified that this increase would be higher in the case of higher planning frequency).

The significant main effect of the factor planning frequency is thus mainly brought forward by its interaction with dynamic order due date maintenance. In the case of high planning frequency, the HSRP is more responsive to changes in the MPS only when dynamic order due date changes are used. This modifies hypothesis 2: frequent replanning on itself is not a guarantee for better performance.

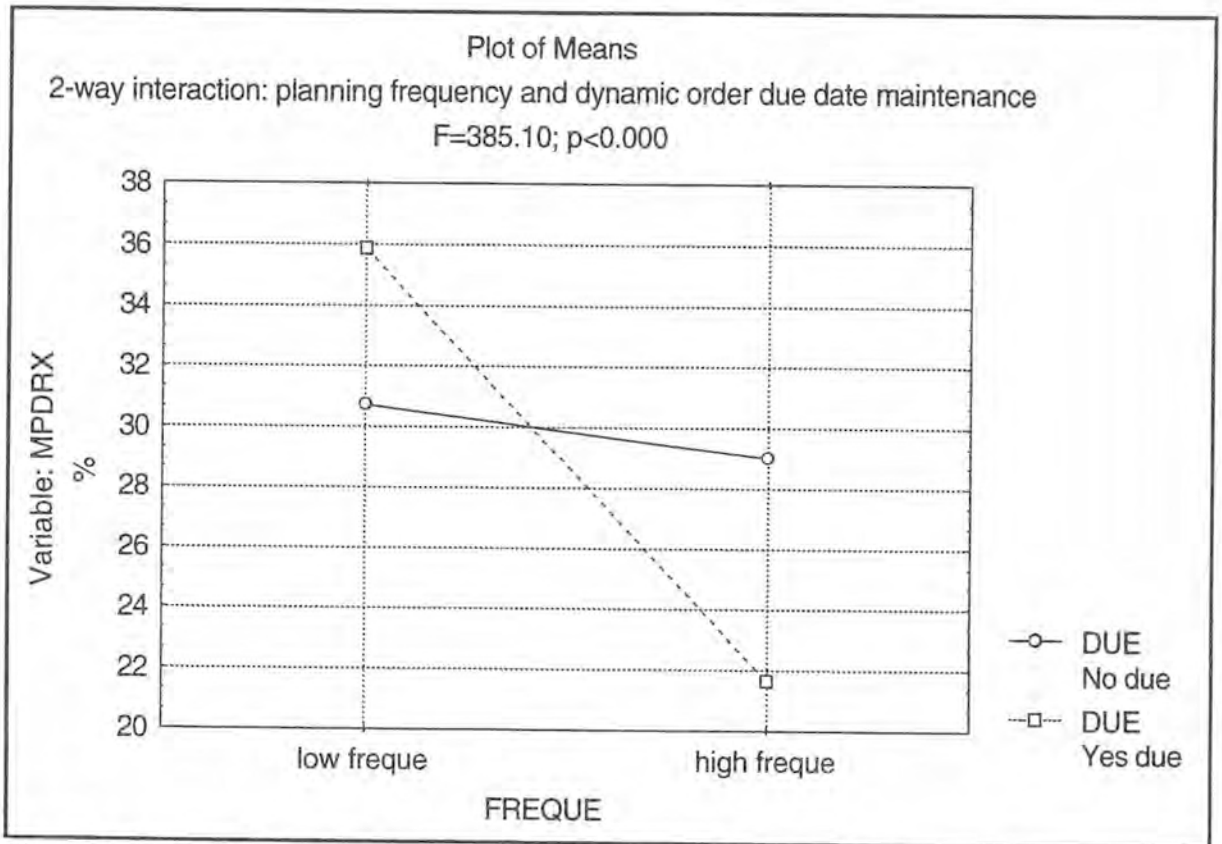

Figure 5.5. Two-way interaction between planning frequency and dynamic order due date maintenance; MPDRX as dependent variable

The three-factor interaction effect in figure 5.6. further shows that safety lead time is also to some extent responsible for the significant improvement in MPDRX in addition to higher planning frequency and dynamic order due date maintenance. Interesting is that a safety lead-time buffer strategy is also a good strategy when the planning frequency is low (or the planning periodicity is one week). The performance of MPDRX with a one week planning periodicity, safety lead-time but without dynamic order due date maintenance (25%) is almost as good as the performance of MPDRX with one day planning periodicity, safety lead-time and dynamic order due date maintenance (21%). A safety lead- time strategy improves the MPDRX in any of the treatments (independent from the presence of a high or low lead-time uncertainty as stated in hypothesis 4).

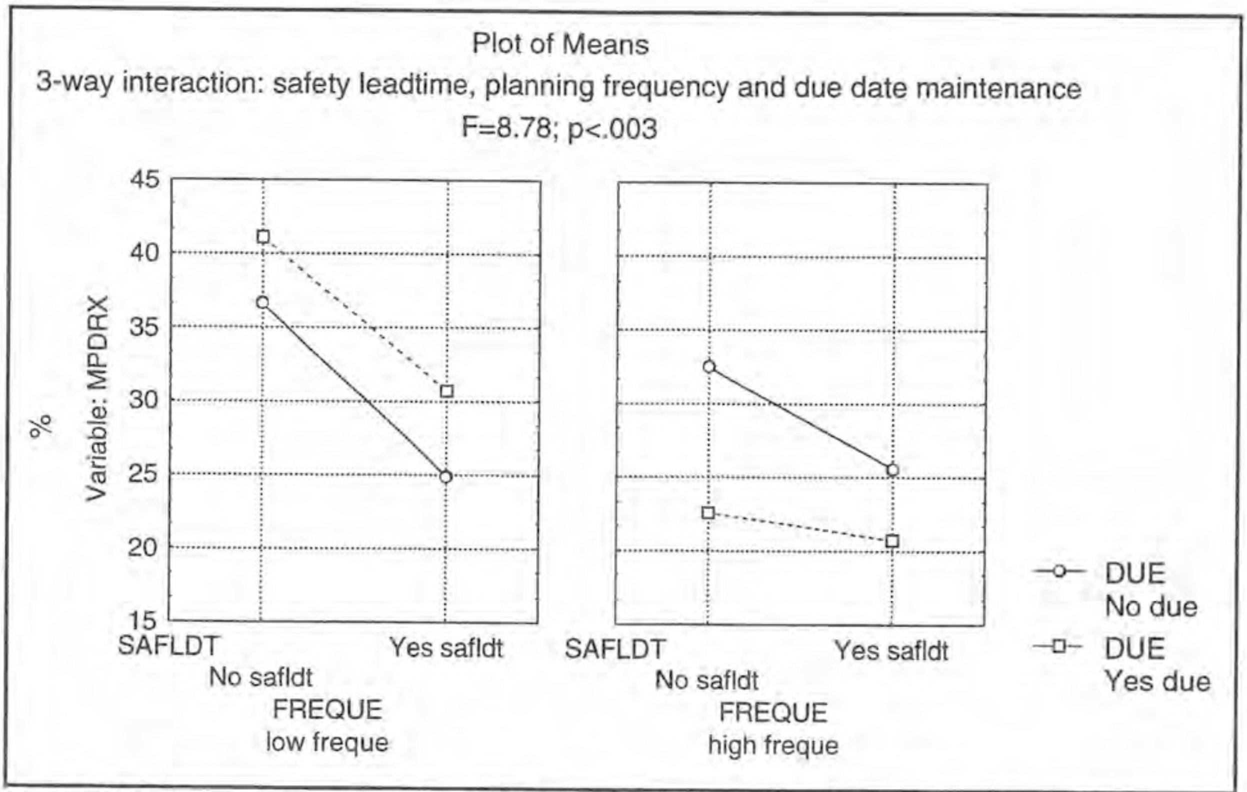

Figure 5.6. Three-way interaction: safety lead-time, planning frequency and dynamic due date maintenance; MPDRX as dependent variable

Safety lead-time seems to be a good strategy to neutralise the negative impact of the classification error (see figure 5.7.). Lead-time uncertainty is best countered by the introduction of higher planning frequency (see figure 5.8.)

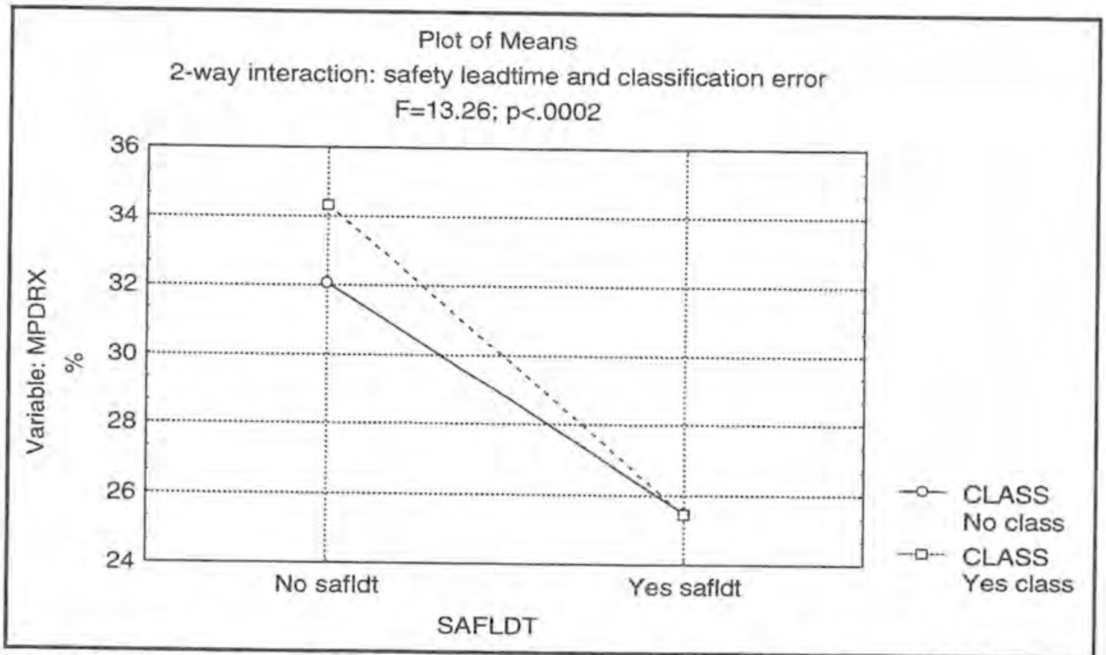

Figure 5.7. Two-way interaction between safety lead-time and classification error; MPDRX as dependent variable

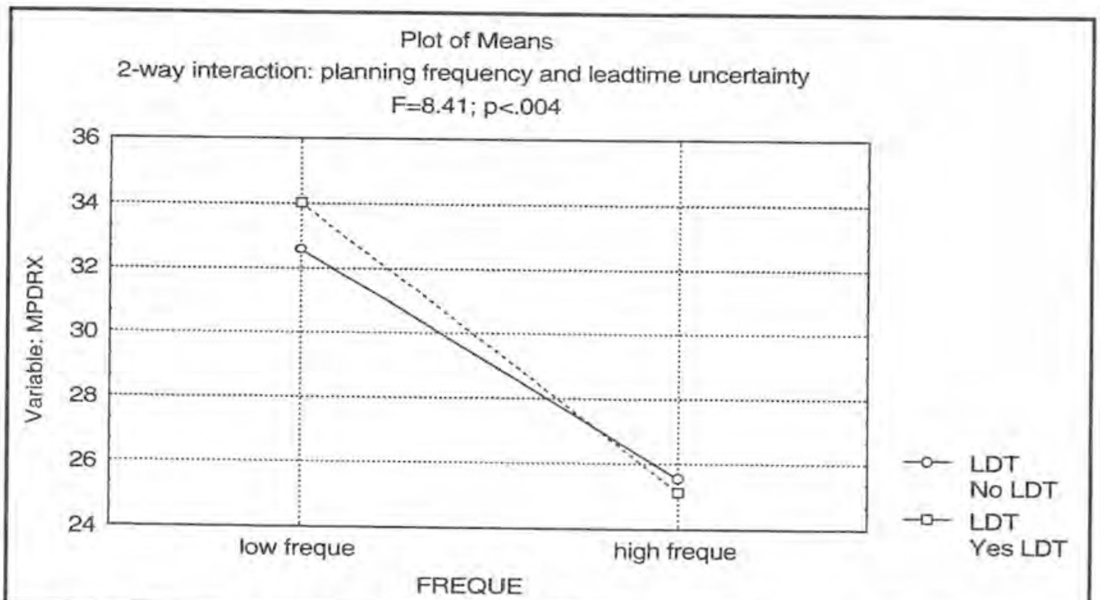

Figure 5.8. Two-way interaction between planning frequency and lead-time uncertainty; MPDRX as dependent variable

Table 5.10. gives a summary of the other significant interaction effects. The table learns that a combination of safety lead-time and dynamic order due date maintenance seems to be a good strategy to reduce the negative effect of capacity limits (124) although due date maintenance is not effective when there are classification errors (126). Safety lead time is also a good strategy to reduce the effect of capacity limits when the planning frequency is low.

The other interaction effects indicate that different strategies to deal with uncertainty are effective in different environments.

Table 5.10. An overview of other significant interaction effects related to MPDRX [88]

Interaction effects	Description
Dynamic order due date maintenance x classification error x planning frequency (167)	This effect mainly shows the negative impact of dynamic order due date maintenance when planning frequency is low (certainly when there is a classification error) and the positive impact when planning frequency is high.
Capacity limits * emergencies * planning frequency (257)	Besides the strong positive effect of higher planning frequency, this interaction effect learns that the negative impact of capacity limits is reduced by the presence of emergencies in the case of low planning frequency
Capacity limits * safety lead-time * planning frequency (247)	The main finding here is the significant positive impact of safety lead-time and planning frequency.
Dynamic order due date maintenance * capacity limits * classification error (126)	Dynamic order due date maintenance always improve planning performance with the exception of the situations where classification error is combined with capacity limits.
Dynamic order due date maintenance * capacity limits * safety lead-time (124)	Safety lead-time has a very strong positive effect on MPDRX. Dynamic order due date has a positive effect only when there are no capacity limits and safety lead-time is not used.

5.2.1.2. ANOVA results for the percentage deviation in actual bed requirements from estimated bed requirements

In the same way, the MPDBED columns of table 5.7. show the ANOVA results for the whole design with MPDBED as dependent variable. All but two of the main effects are significant at $p < 0.01$ level. Table 5.11. shows the direction and amount of the main effect for each of these factors. A move from (-) to (+) level means the introduction of dynamic order due date maintenance, finite capacity, safety lead-time and higher planning frequency. It also means higher lead-time uncertainty, emergencies and classification error.

[88] When the factors of a two-way interaction effect are also included in a three-way interaction effect, only the three-way interaction effect is described in this table.

Table 5.11. Main effects for MPDBED

MAIN EFFECTS	(-) level (in %)	(+) level (in %)
Dynamic order due date maintenance	13.83	14.71
Slack capacity	12.99	15.55
Lead-time uncertainty	13.93	14.61
Safety lead-time	12.52	16.02
Emergencies	13.97	14.56
Classification error	14.14	14.40
Planning frequency	13.48	15.05

The largest surprise in table 5.11 is that none of the significant main effects has a positive impact on MPDBED performance. The analysis of the interaction effects (2,4), (4,6), (4,7), (1,3,4), (1,4,6) and (2,4,7)[89] in table 5.7. learns that a better MPDBED performance is obtained without safety lead times. High planning frequency and dynamic order due date maintenance do not contribute to better results in the prediction of bed requirements (see figure 5.9.). Only when the planning frequency is low, the introduction of dynamic order due date maintenance gives better results. In the discussion in one of the next sections, we give an explanation for this rather unexpected result.

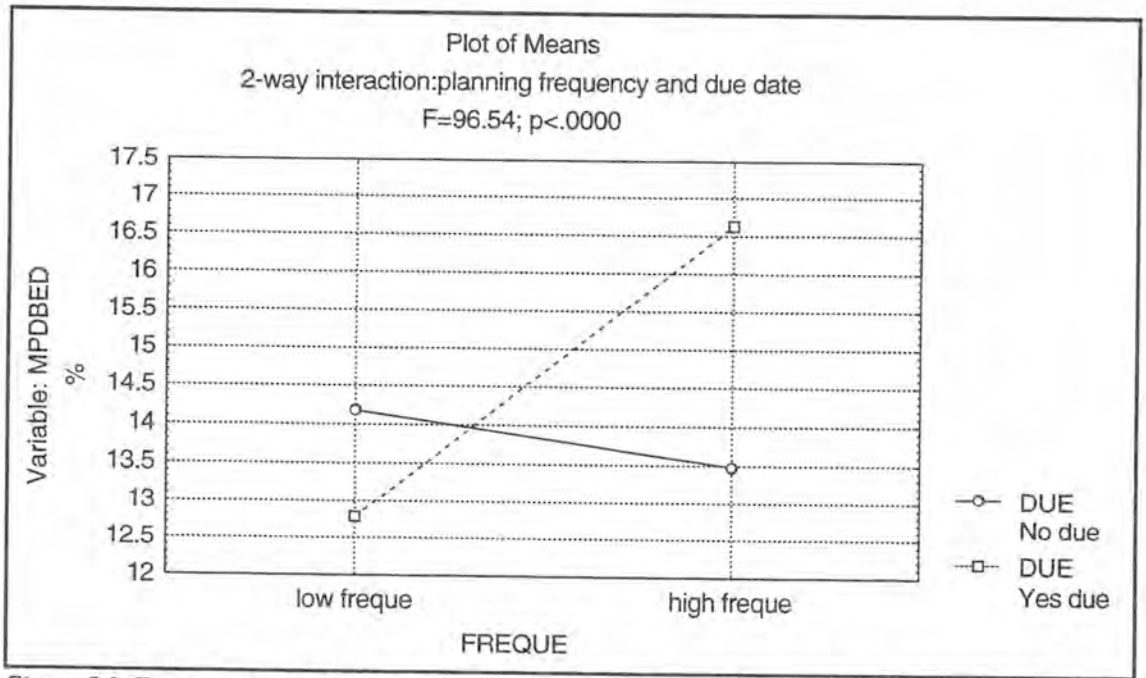

Figure 5.9. Two-way interaction between planning frequency and dynamic due date maintenance; MPDBED as dependent variable

Capacity limits have a significant negative impact on MPDBED. In some specific environments this negative impact can be reduced by dynamic order due date maintenance. Table 5.12.

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[89] We use the notation (2,4) as a means to indicate the interaction effect between the second and the fourth factor where the numbers are the same as in table 5.7.; factor 2 is thus capacity limits and factor 4 is safety lead-time.

shows the other significant interaction effects. Again the table learns that different strategies to deal with uncertainty are effective in different environments.

Table 5.12. An overview of other significant interaction effects related to MPDBED

Interaction effects	Description
Safety lead-time * emergencies * planning frequency (457)	This effect mainly shows the overall negative impact of safety lead-time on bed performance. Only when there are emergencies and when the planning frequency is low, this negative impact is limited.
Capacity limits * safety lead-time * planning frequency (247)	The most important finding is here that when planning frequency is low and there are no capacity limits, safety lead-time has not a lot of impact.
Capacity limits * safety lead-time * classification error (246)	Safety lead time is not a good strategy, certainly not in an environment with capacity limits and/or classification error
Dynamic order due date maintenance * safety lead-time * classification error (146)	This confirms that safety lead-time is never a good strategy in an environment with classification error and with or without dynamic order due date maintenance.
Dynamic order due date maintenance * lead-time uncertainty * safety lead-time (134)	This confirms that safety lead-time is never a good strategy in an environment with lead-time uncertainty and with or without dynamic order due date maintenance. Due date maintenance is not able to suppress the negative effect of lead-time uncertainty when there is no safety lead-time.
Dynamic order due date maintenance * capacity limits * lead-time uncertainty (123)	The most important finding here is that capacity limits have a much stronger negative effect when a strategy of dynamic order due date maintenance is used.
Capacity limits * Emergencies	When there are no capacity limits, emergencies decrease the technical performance. The introduction of capacity limits strongly decreases the bed performance. In this case, emergencies do not further decrease performance.

5.2.1.3. ANOVA results for the mean absolute deviation between the actual discharge date and the most recently updated discharge date (MADCUR)

The MADCUR columns of table 5.7. list the ANOVA results for the whole design with MADCUR as dependent variable. In spite of the higher-level interaction effect, we can conclude that a strategy of dynamic order due date maintenance has a consequent and significant positive effect on the accuracy of the prediction of the discharge date and that safety lead time has a significant negative effect on this technical performance measure (see table 5.13). The former finding is totally in accordance with hypothesis 3 where it is stated that a dynamic order due date maintenance strategy has a significant positive effect on the accuracy of the prediction of the discharge date. The interaction effect between dynamic order due date maintenance and classification error in figure 5.10 learns that dynamic order due date maintenance completely neutralises the negative impact of classification error.

Table 5.13. Main effects for MADCUR [90]

MAIN EFFECTS	(-) level	(+) level
Dynamic order due date maintenance	5.81	4.44
Slack capacity	5.02	5.23
Lead-time uncertainty	5.11	5.14
Safety lead-time	4.69	5.56
Emergencies	5.15	5.10
Classification error	5.01	5.24
Planning frequency	5.11	5.14

Although there are several significant interaction effects, they are not really relevant. For instance figure 5.11 illustrates that higher planning frequency has some positive effect on MADCUR when there are capacity limits, but this effect is smaller than 0.1 day.

[90] A move from (-) level to (+) level means the introduction of dynamic order due date maintenance, finite capacity, safety lead-time and higher planning frequency. It also means higher leadtime uncertainty, emergencies and more classification error.

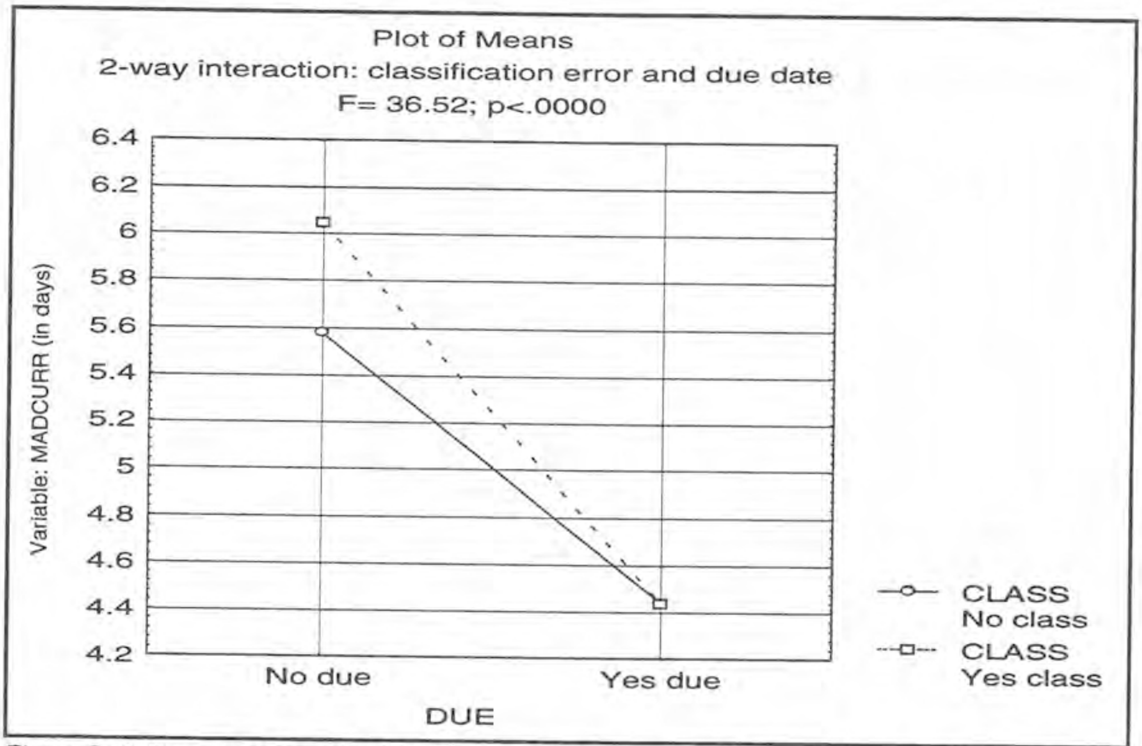

Figure 5.10. Two-way interaction between classification error and dynamic due date maintenance; MADCUR as dependent variable

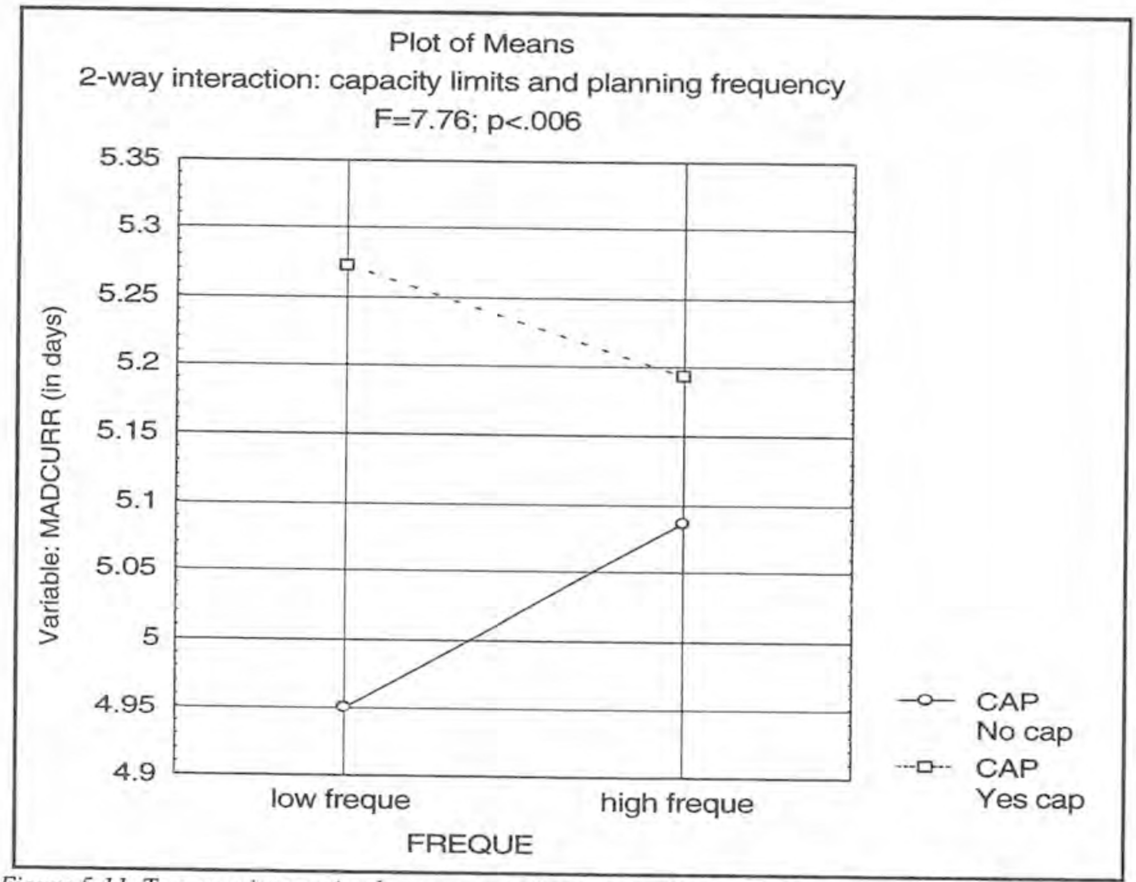

Figure 5.11. Two-way interaction between capacity limits and planning frequency; MADCUR as dependent variable

5.2.1.4. Discussion of the results

One of the most interesting findings in the previous analysis is the opposite behaviour of the two resources (bed and chest X-ray) to the introduction of different strategies to reduce uncertainty in the hospital environment. This means that the kind of resource or the service mix which is involved in the requirements planning is a very important factor. We consider this as a problem related to process uncertainty.

In the case of bed resources, neither combination of dynamic order due date maintenance and high planning frequency nor safety lead-time contributes to better technical performance. In the case of chest X-ray resources, these two strategies are essential to improve the technical performance. Table 5.14 shows the means for MPDBED and MPDRX for those treatments where high planning frequency, dynamic order due date maintenance and safety lead-time are used. If we perform a Wilcoxon matched pairs test on these data, we observe that the technical performance of MPDBED is not different from the technical performance of MPDRX (in contrast with findings in table 5.5.). The null hypothesis that there is no difference between MPDRX and MPDBED cannot be rejected because the calculated value of T (49) is not smaller than the critical value of 30 (see table in appendix 9 for $n = 16$, $p= 0.5$ and two-tailed test). In this specific case, there is a convergence of the performance of the two technical performance measures. In other words introducing the different strategies to reduce uncertainty guarantees a HSRP system which behaves in a similar way for the two different resources.

Table 5.14. Mean MPDBED and MPDRX for those treatments where high planning frequency, dynamic order due date maintenance and safety lead-time are used; Wilcoxon Matched-pairs test.

Treatment	MPDBED	MPDRX
1	15.64	20.08
2	17.62	20.09
3	21.13	19.97
4	21.24	19.65
5	11.14	23.65
6	21.38	19.54
7	23.54	20.54
8	16.65	19.02
9	27.06	20.60
10	17.24	20.09
11	22.83	20.83
12	25.41	22.14
13	22.29	20.87
14	16.86	21.97
15	17.31	21.40
16	17.53	21.47

Wilcoxon Matched Pairs test for MPDRX and MPDBED

	valid n	T	z	p-level
MPDRX & MPDBED	16	49	0.98	0.33

When trying to explain the different behaviour of bed and Rx resources in response to the introduction of different strategies to reduce uncertainty, one has to refer to the different nature of both resources. On the level of one patient, the bed uncertainty is equal to the lead-time uncertainty (or the uncertainty in average length of stay). The uncertainty in Rx consumption is a function of lead-time uncertainty and of the uncertainty concerning the number of procedures consumed during the length of stay in anyone stage. The above results indicate that the proposed strategies are good to reduce the latter uncertainty of resource consumption during the length of stay, but that they are not effective in dealing with lead-time uncertainty. The strong negative impact of safety lead-time on MPDBED further learns that MPDBED is very sensitive to the choice of the average length of stay (in each stage) as the standard lead time. Remind that safety lead-time in this study means that a 'larger than average' standard lead-time is used.

Most of the strategies (with the exception of safety lead time) do not decrease the bed performance in a dramatic way. This is an argument in favour of defining the standard lead-time as an average. Further study must reveal more about the sensitivity of the system to the definition of the standard lead time. Other parameters of the sampling distributions (such as variance) or even theoretical distributions can be considered in modelling the lead time variability.

It is also important to note that the basic situation (without strategies to reduce uncertainty) performs relatively very well in the case of bed resources. Consequently it becomes difficult to further improve this performance.

To produce a further explanatory answer on the basis research question, we have stated 8 hypotheses. In the next paragraphs, we further discuss the results obtained in the framework of these hypotheses. In this discussion, the term 'technical performance' is used in the context of the accuracy of the prediction of resource requirements. We will explicitly indicate when the accuracy of the prediction of the discharge date is discussed.

Hypothesis 1

The higher the uncertainty in the hospital environment, the lower the technical performance of the HSRP system

Although the three sources of uncertainty (lead-time uncertainty, emergencies and classification error) play some role in determining the performance of HSRP, this role is more restricted than hypothesised. The interaction effects of these sources of uncertainty with the strategies to deal with uncertainty are more significant than their main effects. These interaction effects are discussed in the following hypotheses.

We do not find any support for the cumulative negative impact of the three different sources of uncertainty on the technical performance of HSRP. In the case of the percentage deviation in actual resource requirements from estimated resource requirements (MPDBED and MPDRX), none of the significant two- or three-way interaction effects contain two or more of these factors (see table 5.9. and 5.11). This means that HSRP in an environment with two or more sources of uncertainty do not perform worse than in an environment with only one source of uncertainty.

Hypothesis 2

The higher the uncertainty in hospital demand and in the hospital process, the more frequent replanning is necessary to increase the technical performance of the HSRP system.

This hypothesis is only confirmed for chest X-ray resources (which are partially length of stay independent) with the modification that high planning frequency must be accompanied by a strategy of dynamic order due date maintenance to bring forward the expected positive effect. Furthermore, the performance of a low planning frequency combined with a safety lead-time strategy is almost as good as high planning frequency in interaction with dynamic order due date maintenance. Because it is possible to obtain the same technical performance with low planning frequency than with high planning frequency, there seems no reason to use the higher planning frequency in case of MPDRX.

In case of MPDBED, the lower planning frequency seems to perform better than the higher planning frequency, but not in combination with safety lead-time. Only in the case that there are no capacity limits, safety lead-time has not a lot of impact [91]. In this case, we definitely can state that a low planning frequency (i.e. a one week planning periodicity) is preferred above a high planning frequency (i.e. a one day planning periodicity) in the case of MPDRX as well as MPDBED. The relative importance of the two kinds of resources (bed and chest X-ray) determines the choice between high and low planning frequency in the other hospital environments.

Hypothesis 3

By reducing the amount of process uncertainty, a dynamic order due date maintenance strategy increases the technical performance of HSRP. In particular this strategy has a significantly positive effect on the accuracy of the prediction of the

[91] See interaction effect (247) in table 5.11.

discharge date. This increase in performance will be higher when the replanning frequency is higher.

As to MPDRX, we already indicated in the previous hypothesis that dynamic order due date maintenance and planning frequency must go together in order to improve the performance. With low planning frequency, it is not meaningful to introduce a strategy of dynamic order due date maintenance. In the case of MPDBED, the combination of low planning frequency and dynamic order due date maintenance does not produce such negative effects.

There are two indications that dynamic order due date maintenance has a significant positive effect on the accuracy of the discharge date. The mean absolute deviation between the actual discharge date and the most recently updated scheduled discharge date (MADCUR) is consistently better than the mean absolute deviation between the actual discharge date and the original scheduled discharge date (MADHIST). Updates of the scheduled discharge date are only possible through dynamic order due date maintenance. Second, the ANOVA results learn that a strategy of dynamic order due date maintenance has a consequent and significant positive effect on the accuracy of the predictions of the discharge date. In other words, when the MADCUR is the major performance measure, dynamic order due date maintenance is a condition sine qua non.

Hypothesis 4

In the case of uncertain lead times, a safety lead-time strategy improves the technical performance of HSRP in any of the configurations. A safety lead time strategy is even better than holding slack capacity.

In the case of MPDRX, it has already been remarked that the combination of low planning frequency and safety lead time produces a (relatively) good performance. A safety lead time strategy improves the MPDRX in any of the treatments (independent from the presence of a high or low lead-time uncertainty). When the planning frequency is high, safety lead time is able to further improve the MPDRX in addition to a strategy of dynamic order due date maintenance.

In the case of MPDBED, safety lead-time does not produce the expected positive results, certainly not in an environment with increased lead-time uncertainty. [92]

Safety lead time means that a 'larger than average' length of stay is used as standard lead time. Safety lead time is thus strongly related to the way on which a standard lead time is defined. The finding that safety lead time has a positive effect in the case of

[92] See interaction effect (134) in table 5.11.

chest X-ray resources and a negative effect in the case of bed resources further underwrites the importance of the standard lead time in the determination of the performance of HSRP.

Hypothesis 5

The technical performance of HSRP is significantly worse in the case of limited capacity (moderate slack) than when there is infinite capacity (a lot of slack) unless there is a strategy of frequent replanning with dynamic order due date maintenance.
In general, this hypothesis is confirmed, although the slack capacity factor is involved in many different interaction effects. The introduction of capacity limits (finite capacity) significantly increases the fraction of transfers to the ICU which are blocked and the mean proportion of the preoperative patient days which are due to inappropriate use caused by blocked transfers[93]. As a consequence capacity limits significantly increase the average length of stay. This produces a negative effect on MPDRX and an even stronger negative effect on MPDBED.

We do not find any support for a significant interaction between planning frequency, dynamic order due date maintenance and slack capacity. Remind that capacity limits have an effect on the actual length of stay. This means that the distribution of actual length of stay is different in the case of finite capacity than in the case of infinite capacity. The average length of stay (which is used as standard lead time) is probably not able to catch these differences in the form of the distribution.
We have already indicated that there is a significant interaction effect between capacity limits and safety lead time on MPDBED and MPDRX performance when planning frequency is low.

Finally, there is an interesting interaction between capacity limits and emergencies [94]. When there are capacity limits, a hospital environment with emergencies has not a worse performance than a hospital environment without emergencies.[95] In the case of infinite capacity, emergencies do have a negative impact. The most plausible explanation is that the introduction of capacity limits leads to a more stable work flow.

Hypothesis 6

Even with a lot of slack capacity, it can be worthwhile to reduce uncertainty by installing a planning (information) system.

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[93] See next section on planning performance

[94] See interaction effect (257) in table 5.9 and interaction effect (27) in table 5.11.

[95] For MPDRX, this is only true when planning frequency is low.

In fact, there is no indication that the strategies to deal with uncertainty in the case of MPDRX only have a positive impact when there is limited capacity (moderate slack). For instance safety lead time and planning frequency have a significant positive impact on MPDRX independent from the level of capacity slack [96]. As indicated earlier, when there is infinite capacity, emergencies decrease the technical performance of beds so that other strategies to deal with emergencies must be introduced in this environment

Hypothesis 7

The introduction of the classification error strongly reduces the technical performance of the HSRP system in all configurations. This reduction in performance increases when the differences between the DRG categories increase.

When only considering the main effect, this hypothesis is confirmed for chest X-ray resources but not for bed resources. In the case of bed resources, the main effect of classification error is not significant. A plausible explanation is that the average length of stay used as a standard lead time for DRG 104 and DRG 107 patients converges when a classification error is introduced. When DRG 104 patients with a significantly higher preoperative length of stay are 'misclassified' in a DRG 107 category, this leads to a DRG 107 category with patients which have also a high preoperative length of stay as compared with the real DRG 107 patients. This reduces the difference between the two groups so that the average length of stay of DRG 104 is not necessarily significantly different from the average length of stay of DRG 107. In this case, a wrong classification does not produce much effect.

Some of the interaction effects in the previous section show that there is a negative interaction between the classification error - uncertainty of product specification-. and dynamic order due date maintenance. We remind that the dynamic order due date maintenance feature only changes the discharge date in accordance with some more up-to-date information. Because dynamic order due date maintenance assumes interaction between the actual patient flow and the planned patient flow, it is possible to detect classification errors at these points and to reschedule patients in the right DRG-specific MPS. In the current study we have not modelled such behaviour, but probably this will reduce the negative impact of classification error on dynamic order due date maintenance.

[96] See interaction effect (247) in table 5.9.

Hypothesis 8

In the case of high process uncertainty, the technical performance will be significantly better for resources which are completely length of stay dependent (beds) than for resources which are only partially length of stay dependent (chest X-ray).

We find full support for this hypothesis. A Wilcoxon Matched-pairs test confirms that the performance of bed resources is significantly better than the performance of chest X-resources when considering all treatment combinations. When it is found in the previous hypotheses that most strategies to deal with uncertainty have a negative impact on MPDBED while they have a positive effect on MPDRX, than it must be taken into account that the decrease of MPDBED performance is measured relative to a much better starting performance than the measurement of the increase of MPDRX. Even with the negative impact of the strategies to deal with uncertainty on MPDBED, MPDBED is not worse than MPDRX.

The higher-level interaction which is obtained in the different ANOVA-tables (see appendix 10) is an indication that the different strategies to deal with uncertainty have a different effect in different environments. An environment is characterised by the absence or presence of some kind of uncertainty. In order to learn more about for instance the dynamic order due date maintenance strategy, environment-specific studies must be performed. For instance, one can ask which strategy is the best one in the environment of the cardiac surgery department which has been a starting point in this study. The environment has capacity limits on the ICU; there are almost no emergencies; the classification error is low and there is lead-time uncertainty but not to some high extent. In this case we have an experiment with three factors (dynamic order due date maintenance, safety lead-time and planning frequency). Table 5.15 shows the ANOVA-results for this design and figures 5.12 and 5.13 show the significant three-way interaction effects. The results are very similar to the general results. When considering chest X-ray resources (figure 5.12), a strategy of safety lead-time with low planning frequency and no dynamic order due date maintenance, or a combined strategy of high planning frequency, dynamic order due date maintenance and safety lead-time can be suggested. Taking into account that the latter strategy leads to higher operational costs, the former strategy (with low planning frequency) can be preferred.
At the other hand, safety lead time is not a good strategy for reducing the uncertainty in the bed requirements (figure 5.13). In fact the basic strategy (no safety lead time, no due date maintenance and low planning frequency) performs very well.
In this case, we could give the advice to use a system in which safety lead time is introduced, with a one week planning periodicity and with no dynamic order due date maintenance. This advice assumes that both resources are equally important for the resource management in the

hospital. Of course the final advice depends on the relative importance of the two kinds of resources.

Table 5.15. ANOVA results for MPDRX and MPDBED in the specific case

	MPDRX	MPDRX	MPDBED	MPDBED
Source	F-value	P-level	F-value	P-level
1	0.64	0.430073	16.18	0.000329
2	32.99	0.000002	40.48	0.000000
3	4.56	0.040514	8.48	0.006491
12	8.64	0.006071	5.41	0.026525
13	41.09	0.000000	39.05	0.000001
23	0.09	0.764834	0.00	0.939490
123	8.51	0.006422	12.81	0.001124
df effect = 1 df error = 32 Ms error = 12.62564			df effect = 1 df error = 32 Ms error = 8.733232	

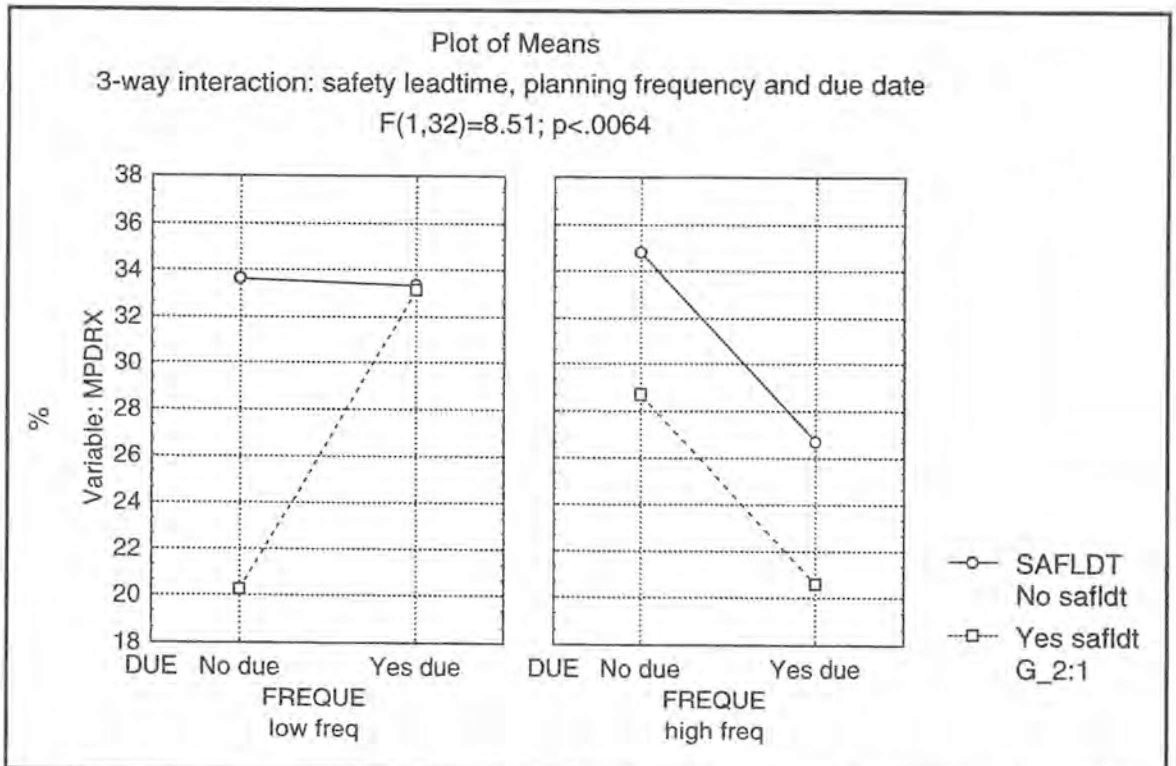

Figure 5.12. Three-way interaction effect between safety lead-time, planning frequency and dynamic due date maintenance in the specific situation of cardiac surgery; MPDRX as dependent variable.

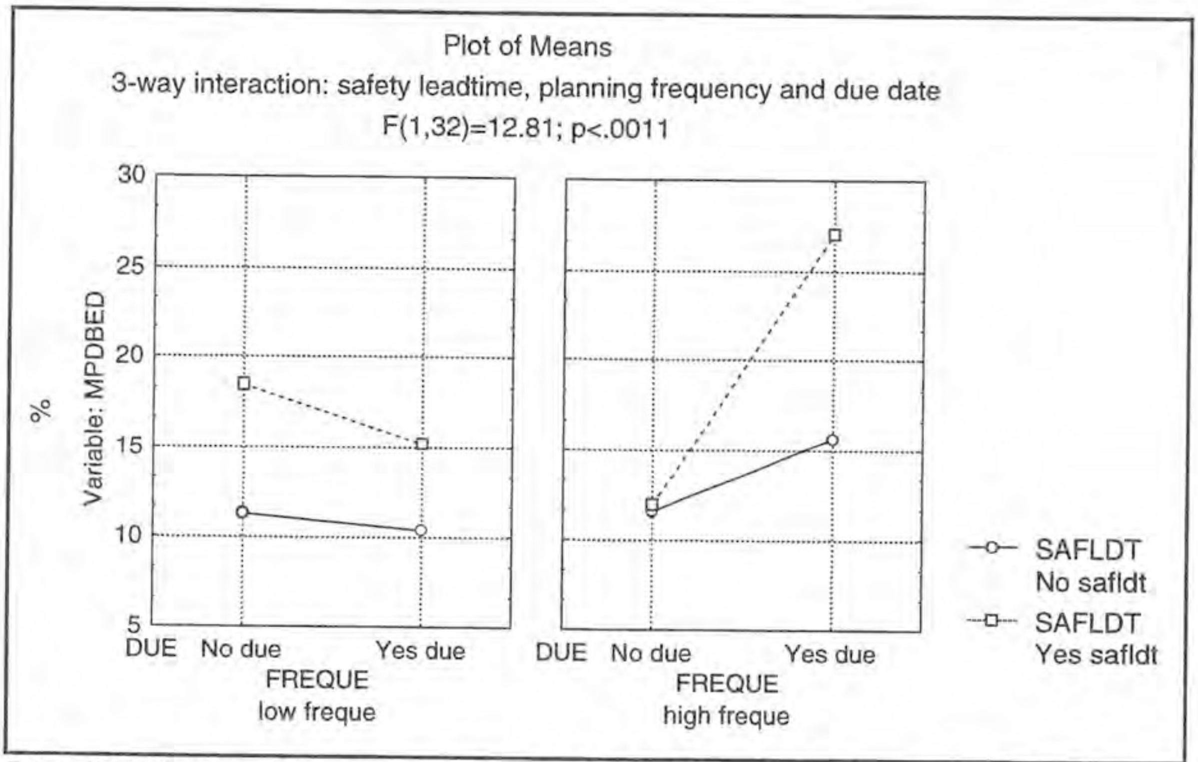

Figure 5.13. Three-way interaction effect between safety lead-time, planning frequency and dynamic due date maintenance in the specific situation of cardiac surgery; MPDBED as dependent variable

5.2.2. The planning performance of HSRP

In the basic experiments, the HSRP output does not support management decisions concerning the allocation of resources or the management of the patient flow. This means that the actual resource requirements as obtained in the simulation are not influenced by the working of HSRP. We do not investigate the planning performance because our first objective is to evaluate the behaviour of HSRP in an environment with different sources of uncertainty, and the modelling of planning decisions assumes comprehensive changes in the simulation model.

In further experiments, the simulation model must be expanded to include planning decisions so that the planning performance can be evaluated. We propose to perform experiments for some specific environments so that the number of experimental factors is reduced.

Because several of the planning performance measures are also an indication of the operating performance of the hospital, it is still meaningful to look at these measures. In performing ANOVA with measures such as length of stay as dependent variable, we do not find any unexpected results. The results are more a confirmation of the operational validity of the model. The introduction of capacity limits (finite capacity) significantly increases the fraction of transfers to the ICU which are blocked ($p < 0.00001$) and the mean proportion of the preoperative patient days which are due to inappropriate use caused by the blocked transfers (p

< 0.00001). As a logical consequence, capacity limits also significantly increase the average length of stay ($p < 0.00001$) (see figure 5.14). Another logical result is that the capacity limits decrease the standard deviation of the utilisation of the ICU department (8327) and of the medical heart surgery department (8140) (both at $p < 0.00001$ level). Finally patients have not to wait before admission because until now the admission scheduling procedure does not take into account resources such as operating room.

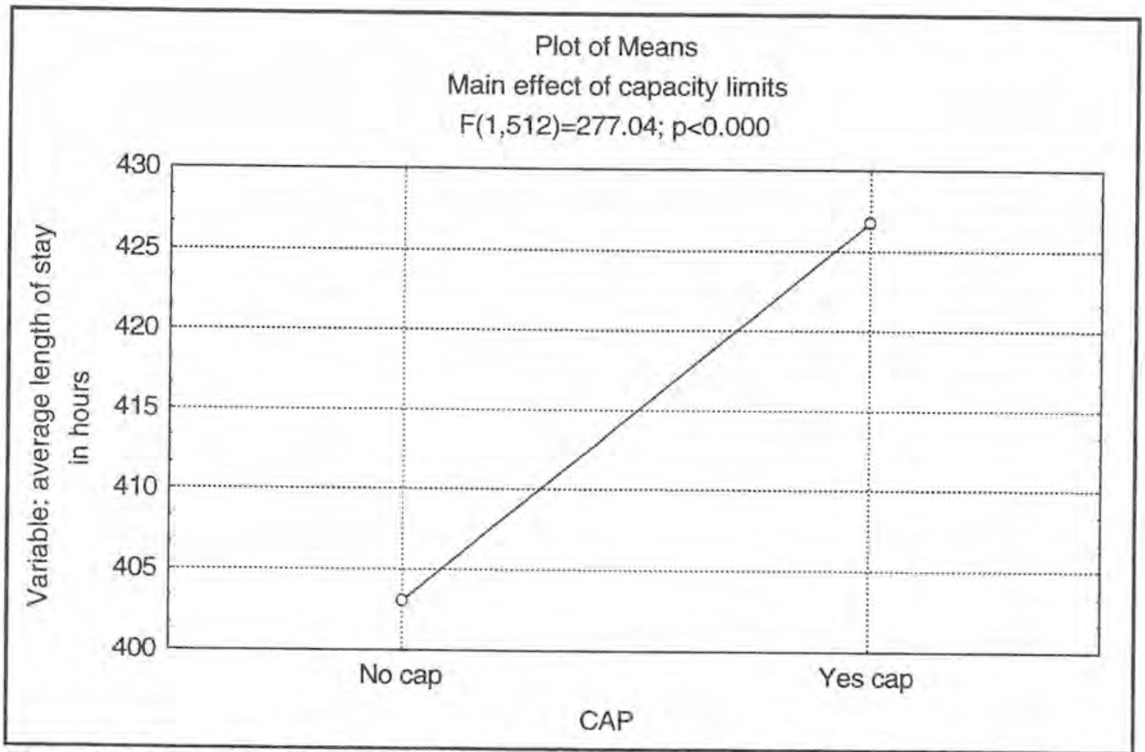

Figure 5.14. Main effect of capacity limits; average length of stay as dependent variable

6. CONCLUSION AND FURTHER RESEARCH QUESTIONS.

In this part, we summarise the main research contributions and management contributions of the study. Finally, we describe the further research questions.

6.1. The research contribution

In section 3.1. we formulated the basic research question as follows: "What is the performance of the HSRP system (based on MRP concepts) in a hospital environment taking into account the different sources of uncertainty and the different strategies to reduce or to buffer against uncertainty ?". In fact, this is a question about the feasibility of the HSRP system in different hospital environments. In this study we only deal with the technical feasibility and not with the feasibility of HSRP as a support tool for planning decisions.

The study has contributed to the discussion about the feasibility of an MRP-based HSRP system for service requirements planning in a hospital. As to the technical performance of the HSRP system, we can state the following conclusion:

As to the technical performance of HSRP, we cannot conclude definitely whether the system is feasible for a hospital environment. The current study has allowed to identify those factors which are important in determining the technical performance of HSRP: the extent to which resources are length of stay dependent and the way on which one deals with lead time uncertainty, more specifically variability in the length of stay.
The extent to which resources are length of stay dependent has a double impact on the performance of HSRP:
1. The estimation of the requirements for resources which are length of stay dependent is significantly better than the estimation of the requirements for resources which are not length of stay dependent.

2. The different strategies to deal with uncertainty have a clearly better effect on the accuracy of the estimations of the requirements for resources which are length of stay independent than on the accuracy of the estimations of the requirements for resources which are length of stay dependent.

When looking at tables 5.1. and 5.2. in the previous section, we find a range of technical performance in terms of mean percent deviation in actual resource requirements from estimated resource requirements going from 9.55% to 57.99%. Although we did not set any norms as to what is good or bad performance, a mean percentage deviation of 58% is not all acceptable. We also observe in table 5.13 that when the HSRP is enhanced with its design factors to deal with uncertainty, the technical performance has a range going from 11.14% to 27.06%. In the study of Cheng (1987) who used the same performance measure, this range of mean percent deviation is evaluated as being associated with more extreme forms of process uncertainty which must be reduced as much as possible. We have to remind that cardiac surgery patients (which are subject of this study) are better schedulable than many of the medical patient groups. In other words, other patient groups may experience more uncertainty which can lead to lower technical performance. It can be concluded that more standardisation in the service delivery process in a hospital is a condition sine qua non for service requirements planning. **Because standardisation is more easily obtained for surgery cases than for medical cases, we suggest in any way to limit the application of HSRP to the former group of patients.**

A hospital environment has been characterised by the presence of several resources of uncertainty to different degrees. We have classified the sources of uncertainty as uncertainty of product specification, mix and volume uncertainty of future demand and process uncertainty. One of the clear findings in this study is that process uncertainty, and more specifically the certainty about the service-mix requirements plays a very significant role in the performance of the HSRP system. **The hypotheses in this study are generally more confirmed for chest X-ray resources than for bed resources.** The different behaviour of bed resources (which are length of stay dependent) and chest X-ray resources (which are length of stay dependent in some departments and length of stay independent in other departments) learns that implementing HSRP requires a very careful study of which resources are included in the system and of the characteristics of these resources.

In trying to explain the different behaviour of these resources, we formulated the new hypothesis that **the choice of the average length of stay as standard lead time strongly influences the performance of HSRP with particular kinds of resources.** The way on which a length of stay distribution is summarised, is more important in determining the HSRP performance than we thought. In this context, the findings introduce some doubts about the use of means in developing the bill of resources. For short-term planning, one should consider the use of a measure of variability (Roth et al., 1992).

The feasibility of the HSRP system also depends on some design factors which can be added: safety lead-time, dynamic order due date maintenance and planning frequency. **The kind of impact these strategies have depends on the kind of resource requirements which are planned.** In the case of the chest X-ray resources, these strategies have the expected positive impact while in the case of bed resources, these strategies have an unexpected negative impact on the technical performance. We have already indicated that these opposite effects are probably related to the definition of the standard lead-time as an average length of stay. The result of these opposite effects is that the mean performance of both resources approximately becomes equal. This means that a system with dynamic order due maintenance, high planning frequency and safety lead-time can be applied independent from the nature of the resources. It then becomes important to look for other strategies or HSRP features which allow to improve the performance of the whole system.

6.2. The contribution to the area of hospital management

The contributions of the study to the area of hospital management can be organised around three of the four design characteristics of HSRP: (1) capacity structure; (2) patient flows and Diagnosis-related Groups and (3) case-based resource management data.[97] Finally we formulate some (4) other management contributions which are related with this study.

6.2.1. Capacity structure

The most important research finding that different kinds of resources behave completely different in the requirements planning system is also very important for hospital managers. **The first task in developing a more integrated planning system is to study the capacity structure of the hospital and to classify the resources in more homogeneous groups according to some criteria**. This study reveals that the degree of length of stay dependency is a very important criteria. This classification is not an easy exercise because some resources are length of stay dependent in some departments (such as chest X-ray in the intensive care unit) and length of stay independent in other departments (such as chest X-ray in the medical care unit).

Integrated service requirements planning does not mean that all resources must be included in the planning system. It is important to identify the leading resources and the bottleneck resources. Once the leading resource is scheduled, other following resources can be easily scheduled without any formal procedure under the assumption that the following resource is not a bottleneck resource.

6.2.2. Patient flows and Diagnosis-related Groups

Planning resources for patients at the moment of admission scheduling requires knowledge about the expected resource use. This is only possible when the care and treatment needs of a patient are identified as a certain product. In the past, the main barrier for an operations

[97]The fourth characteristic 'transfer of manufacturing planning concepts' has been discussed in the previous section.

management view on the hospital process was the absence of a clear understanding of 'what constitutes a product of a hospital. The introduction and diffusion of patient classification systems such as diagnosis-related groups brought a general accepted way of describing the output of a hospital. Although diagnosis-related groups are generally accepted in Belgium, we have introduced some doubts about the use of this system for internal management purposes, and more specifically for service requirements planning. **The ultimate selection of DRGs as product line definition is chiefly based on practicality considerations, but the question is whether practicality considerations will continue to dominate the selection decision when software for other patient classification systems such as Patient Management Categories become generally available at affordable price through a larger diffusion over the world.**

6.2.3. Case-based resource management data

As to the collection of case-base resource management data, we give two suggestions based on the experience in this study:

A hospital must increase its capability to process more information. Hospitals are traditionally structured as complex organisations with a focus on the internal operations of functional departments and medical units. The treatment of patients requires a network of relationships between mainly professional groups which have partial information. Hospital service requirements planning increases the capability of the hospital organisation to collect information which is scattered over the organisation. This can only be obtained when the individual patient is the basic unit for data collection.

Attention must be paid to the development of measures of resource use. A measure of resource use is a unit of service that indicates the quantity of a hospital service consumed by the patient. Measures of resource use require the merging of clinical and financial data with the patient as common denominator. The development of such measures is not only important for service requirements planning, but also for case-mix cost accounting.

6.2.4. Other management contributions

Hospital managers often argue that their organisation is different because of the uncertainty in the hospital service delivery process. In this study, we have offered a framework to identify the different sources of uncertainty. The traditional supply-demand distinction does not well fit the hospital environment. We propose to use three categories of uncertainty which have been useful in the engineer-to-order environment: **uncertainty of product specification, mix and volume uncertainty of future demand and process uncertainty**. We have proved that this is a useful framework to characterise the specific hospital environment in which one is working.

As in the case of the heart surgery department of the University hospital in Gent, the current simulation model allows to give some advice about the characteristics of a service requirements planning system which best fits a specific environment. A study of a specific environment - this may be a department or a group of departments in the hospital-, can give some insights in how the different parameters in the model must be valued.

6.3. Further research questions

A first step in the further study of HSRP is an investigation of the planning performance of HSRP. Second the unsatisfactory results with the technical performance of HSRP in the current design encourage two different streams for further research: (1) the study of other strategies to (further) improve the technical performance of HSRP and (2) the study of other approaches to perform the task of service requirements planning. The restriction of the research topic to two cardiac surgery patient groups also includes some further perspectives for further research. Finally, a series of questions are related to some organisational and implementation considerations and to software development.

6.3.1. An investigation of the planning performance of HSRP

Until now, we have only studied the technical performance of HSRP, i.e. the ability of HSRP to predict future resource requirements. HSRP must support capacity planning decisions so that better capacity utilisation and shorter throughput times are achieved. Once the technical performance of HSRP is satisfactory, one need to test the planning performance of HSRP. To test the planning performance, one must simulate a planning decision process in the model. One example of such decision is the admission scheduling process where admissions are scheduled taking into account the resources required for other patients which are already scheduled. The purpose of this kind of admission scheduling is to avoid peaks and valleys in the work load of service units. It is possible that this kind of admission scheduling improves the technical performance of HSRP because of the stability which is introduced in the daily utilisation of (one or more) resource(s). In this study we did not investigate the planning performance of HSRP because this assumes comprehensive changes in the simulation model. We have identified relevant criteria to measure planning performance.

6.3.2. Other strategies to further improve the technical performance of HSRP

During the discussion in the previous part, we have already identified some other strategies to deal with the different resources in a hospital environment. There are for instance possibilities to have more points during the flow of patients where the actual flow time is compared with the planned flow time. Based on this comparison, the discharge date in the MPS can be

changed so that the MRP explosion works with more up-to-date data. This is an extension of the dynamic order due date maintenance strategy. We have already proposed another extension. At the moment that planned and actual flow times are compared, it can be checked whether the diagnosis of the patient is changed so that she/he need to be classified in another DRG and thus in another MPS.
Remark that for such extensions, one need to know the scheduled admission date as well as the admitting diagnosis of the patient in order to track the patient in the scheduling system. This means that each patient is considered as a project for which some milestones are defined. Each milestone is a check-point to fine tune the schedule with the actual flow. The throughput time in each schedule is individualised for a patient. The original bill of resources is in other words 'generic' for the lead-times related with each level. This also means that the discharge dates in the MPS are not anonymous, but are linked with a specific patient. Although the progress of the patient is tracked, the production progress of all services and activities for a specific patient are not followed. These services are still independent from the specific patient. Otherwise it is useless to define product groups such as DRGs. In other words the service delivery process is not considered as an engineer-to-order but as a make-to-order environment. Further enhancements to HSRP may not lead to a situation where the production progress of all services must be tracked for a specific patient. More project-oriented tools such as CPM-MRP are probably more adapted to deal with this situation.
Tracking of the progress of the patient is quite realistic because most hospitals have a database with data on the length of stay of every patient in each department. This means that this event-history database must be linked with HSRP.

There are still some other strategies to deal with uncertainty which have not been included in this study. The most important one is forecasting. Forecasting does not add any value when measuring technical performance as the percentage deviation of estimated resource requirements from actual resource requirements because the estimated resource requirements as registered on the current day cannot be influenced by forecasts. When measuring planning performance, forecasting is probably an important factor in taking accurate planning decisions. For instance, when management takes a decision -based on HSRP output- to change the capacity level of nurses for the next week, this management must take into account the number of emergencies they expect to arrive in the next week.

6.3.3. Other approaches to perform the task of service requirements planning.

Although we still believe in the comparative added value of a MRP-based HSRP system, we may not be blind for other evolutions which can bring forward a decision support tool for service requirements planning. Clinical pathways which are enhanced with measures of

resource use can serve as a real-time and patient-based service requirements planning system. This is even more true when these clinical pathways are automated.
Furthermore, we have to take into account current evolutions in simulation modelling where user-friendly and environment-specific simulators allow to more easily introduce the stochastic service delivery process in a planning algorithm. These possibilities of finite capacity scheduling are much greater with such tools.

6.3.4. Generalisation of the findings

During the design of the study, we have restricted the research area to two categories of cardiac surgery patients in one acute care inpatient hospital. One stream of further research must focus on the generalisation of the findings to a system working with more patient groups (DRGs) and more departments. One problem in the current study is that the four DRG categories are not fundamentally different in their pattern of resource consumption. When DRGs out of different MDCs are used, the resource consumption pattern can show more fundamental differences. This has a lot of consequences on the performance of HSRP. The negative impact of a case-mix error is probably much higher when the differences in consumption pattern are greater. In the other hand, the use of averages in the bill of resources is more meaningful when the consumption patterns are clearly different. By expanding the current simulation model, it is possible to answer some of these questions.
Furthermore, one can ask the question whether the approach of HSRP is useful for other health care organisations such as one-day clinics. The short service encounter in one-day clinics requires a very accurate planning system integrating the different services which must be delivered.

6.3.5. Organisational and implementation dimensions

During the study, we have become increasingly aware that the implementation of a HSRP system in a hospital completely depends on the willingness of the physicians to accept a more formal and centralised planning system. This has two important implications: (1) the system must prove to add some particular value to the professional goals of the physicians and (2) the physicians must be involved in the development of the system. Because HSRP strongly supports the timeliness of service delivery, it is not difficult to prove the added value of the system. Furthermore, HSRP does not schedule physicians, but it schedules the services and the resources which are needed to satisfy the service demands of physicians.

During the study, we observed an increased use of practice guidelines and clinical pathways in the service delivery in hospitals and we advised to link measures of resource use to these tools. Although these tools do not reduce uncertainty, they reduce variability in the system. The main condition for obtaining such improvement is that the health practitioners are involved in the development of such tools and that they try to continuously improve their practice. This is the only way to assure that the measures of resource use used in service requirements planning are based on required resource utilisation and not on observed resource utilisation.

A restructuring of the hospital in more or less autonomous units which are treating resource-homogeneous patient groups significantly reduce the complexity of hospital service requirements planning. Such structuring has been proposed in the so-called Patient-Focused Hospital (Lathrop, 1993). Service requirements planing is a patient-focused management tool because it considers the patient as the final output of all (clinical and ancillary) departments in the hospital.

6.3.6. Software development

At this moment, the working of HSRP is simulated in a model. A more large-scale application of HSRP must be sustained by appropriate software. The findings in this study learn that it will be difficult to adapt standard MRP software in a hospital environment. We believe that the ultimate software package will contain MRP-based features and medical informatics based features. This means that an interdisciplinary approach will be necessary to develop the software.

In the different hospitals we have visited during the execution of this study, we have observed that managers, specialists and nurses are increasingly aware of the necessity to better manage their resources. Although, HSRP is already a more advanced application of internal resource management, the basic assumptions underlying the system are managerial guidelines in how better resource management within hospitals can be achieved. The more these guidelines are followed, the more HSRP will become an indispensable tool in internal resource management. Therefore, we believe that the research on designing a HSRP system which fits the hospital environment must be continued.

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A SIMULATION-BASED EXPERIMENTAL INVESTIGATION OF A HOSPITAL SERVICE REQUIREMENTS PLANNING SYSTEM UNDER DIFFERENT SOURCES OF UNCERTAINTY

Research summary

Paul Gemmel

Introduction

The whole hospital sector is under growing external pressures to operate in an efficient way. This study is a contribution to this search for efficiency from an operations management point of view. More specifically, this study develops and tests the feasibility of a system for planning the requirements for services in an acute care inpatient hospital. The research outline is shown in figure I. In the next sections, we shortly discuss each of the main steps in the research outline.

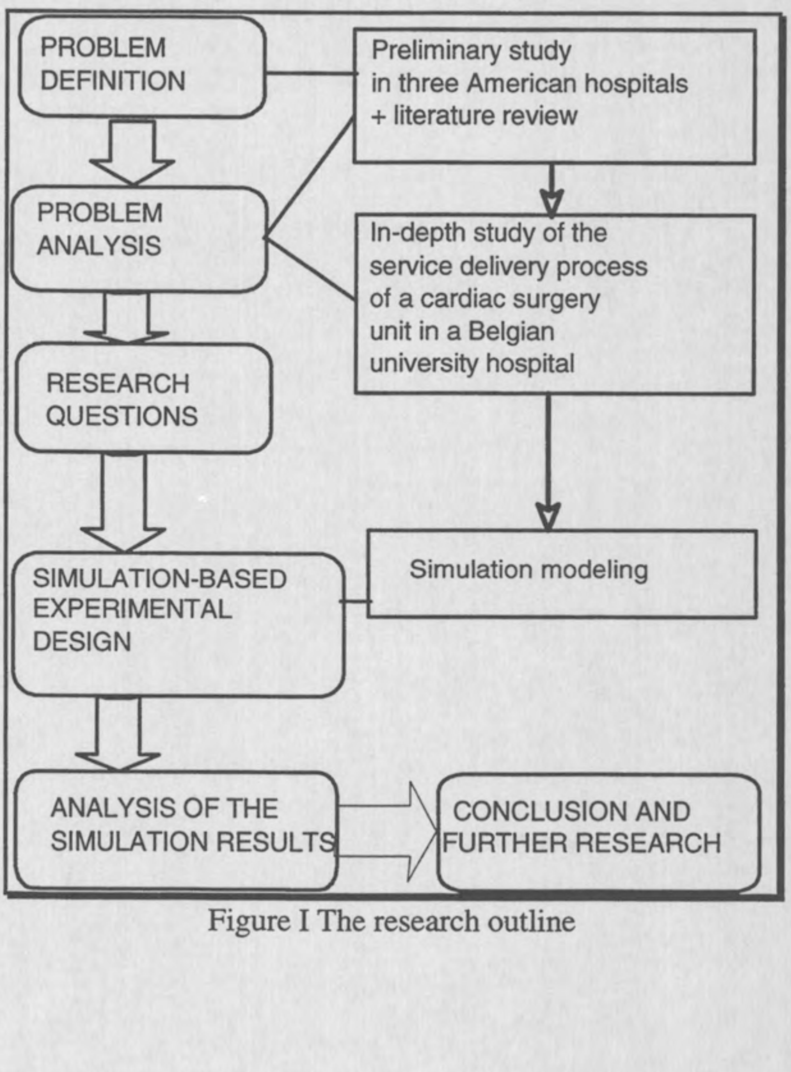

Figure I The research outline

Problem definition

After an extensive review of the literature and after a preliminary study in three American acute care hospitals, we found that one of the main barriers in obtaining higher efficiency in the hospital operations is the lack of an integrative approach in the process of matching the capacity of several hospital resources (such as beds, operating rooms and nursing staff) with the demand (i.e. the inflow of patients). Matching supply and demand is the core task of capacity management.

Service requirements planning in inpatient acute care hospitals is a process which supports capacity management decisions by treating demand for hospital services in terms of all of the resource requirements associated with a certain patient and with the objective of balancing and stabilising the utilisation of resources . The aim of hospital service requirements planning is to break through the dilemma between better capacity utilisation and shorter throughput times. Better capacity utilisation does not necessarily mean higher utilisation, but means less fluctuation in the daily utilisation or workload pattern. We argue that workload fluctuation is recognised as one of the major problems in obtaining higher efficiency in health service delivery.

Problem analysis

To perform the task of service requirements planning in hospitals, Roth et al. (1992) propose a decision support system which is called HSRP (Hospital Service Requirements Planning). The design of this system is based on four important assumptions:

1. HSRP requires the definition of patient groups which are homogeneous as to their consumption of hospital resources. In this study we have decided to use the Diagnosis-related Groups (DRGs) as a way to define resource-homogeneous patient groups.

2. There are relationships between the capacity of different service units in a hospital and these relationships must be reflected in the planning system. We use the term 'capacity structure' for such relationships. In HSRP, the capacity structure of the hospital must be built in. Tools such as 'bill of resources' and 'MRP mechanism' are used for this purpose.

3. Clinical and financial data on the patient can be merged so that measures of resource use can be obtained.

4. The planning algorithm of HSRP is based on concepts which are transferred from the manufacturing planning and control environment to the hospital planning and control environment. Master Production Scheduling (MPS), bill of resources and Manufacturing

Requirements Planning (MRP) are the three most important manufacturing concepts which have been transferred.

The HSRP as proposed by Roth et al. (1992) is a conceptual framework and requires further validation to find out whether the transferred concepts are useful and meaningful. This study brings some validation taking into account the differences between the hospital and manufacturing environment. The general research framework is shown in figure II.

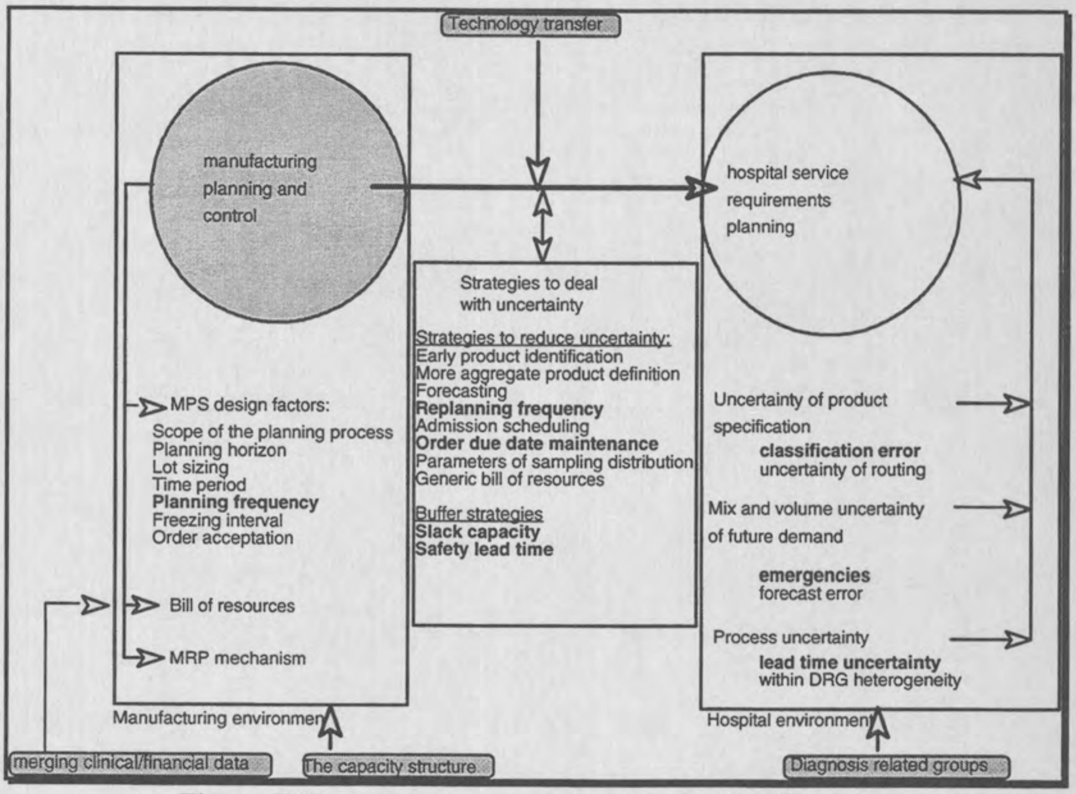

Figure II The general research framework for this study.

The main difference between the hospital and manufacturing environment is that there is a lot more uncertainty in a hospital than in the manufacturing environment where the transferred concepts are traditionally applied. Based on an in-depth study of the service delivery process in a cardiac surgery department in a University hospital, we identified the major sources of the uncertainty in the hospital operations (see right part of figure II).

We also identify strategies to deal with these different sources of uncertainty. A distinction is made between strategies to reduce uncertainty and strategies to buffer against uncertainty (see middle part of figure II). These strategies can be used with or incorporated in the HSRP system.

Research questions

The basic research question is formulated as follows: "What is the performance of the HSRP system (based on manufacturing planning concepts) in a hospital environment taking into account the different sources of uncertainty and the different strategies to reduce or to buffer against uncertainty ?". We want to evaluate the feasibility of the HSRP system in hospital environments taking into account that some design factors of HSRP can be changed in order to better fit a specific hospital environment. The specificity of the hospital environment is determined by the extent to which the different sources of uncertainty are present in the hospital environment. The most important result in the study should be the identification of the factors (sources of uncertainty and/or design characteristics) which significantly determine the performance of the HSRP system.

A distinction is made between the technical and the planning performance of HSRP. We only study the technical performance of HSRP, i.e. the accuracy of the estimations of the service requirements as compared with the actual service requirements, and the accuracy of the prediction of the discharge date as compared with the actual discharge date.

Because of the large number of factors, we have made a selection of factors which are included in this particular study (see the bold factors in figure II).

Simulation-based experimental design

The main ingredients of an experimental design are the previous mentioned factors and performance measures (called responses). The different factors and responses are linked through hypothesis statements. We stated the following conceptual hypotheses:

1. The higher the uncertainty in the hospital environment, the lower the technical performance of the HSRP system

2. The higher the uncertainty in hospital demand and in the hospital process, the more frequent replanning is necessary to increase the technical performance of the HSRP system.

3. By reducing the amount of process uncertainty, a dynamic order due date maintenance strategy increases the technical performance of HSRP. In particular this strategy has a significantly positive effect on the accuracy of the prediction of the discharge date. This increase in performance will be higher when the replanning frequency is higher.

4. In the case of uncertain lead-times, a safety lead-time strategy improves the technical performance of HSRP in any of the configurations. A safety lead-time strategy is even better than holding slack capacity.

5. The technical performance of HSRP is significantly worse in the case of limited capacity (moderate slack) than when there is infinite capacity (a lot of slack) unless there is a strategy of frequent replanning with dynamic order due date maintenance.

6. Even with a lot of slack capacity, it can be worthwhile to reduce uncertainty by installing a planning (information) system.

7. The introduction of the classification error strongly reduces the technical performance of the HSRP system in all configurations. This reduction in performance increases when the differences between the DRG categories increase.

8. In the case of high process uncertainty, the technical performance will be significantly better for resources which are completely length of stay dependent (beds) than for resources which are only partially length of stay dependent (chest X-ray).

Because the HSRP system is in no way an operational planning system, we cannot set up an experimental design or quasi-experimental design through the implementation of the system in an actual operating hospital. When experimentation with the actual system is not possible, we have to experiment with a model of the system. We have chosen to simulate the behaviour of the real system, i.e. (a part of) an actual operating hospital. The feasibility question of HSRP is tested in this 'artificial' environment. Furthermore, because HSRP is not operational, we have also simulated the working of this service requirements planning system. Modelling systems requires a very rigorous methodology to assure that the results obtained with the model are credible. To obtain such credibility, we spend a lot of time at the validation and the verification of the simulation model.
In order to be able to simulate the operating system of a part of a hospital, we have performed an in-depth study of the service delivery process in a cardiac surgery unit of a University hospital in Belgium.

Analysis of the simulation results

A Wilcoxon Matched Pairs-test confirms hypothesis 8 that the technical performance of HSRP in the case of bed resources is significantly better than in the case of chest X-ray resources. In order to further analyse the simulation results and to formulate an answer on the other hypotheses, we have used one-way ANOVA. Using ANOVA, one gets an indication of the question whether the different levels of the factors play a significant role in the determination of the dependent variable (in this case the technical performance measures). Regarding conditions for ANOVA's applicability, the requirement of independent data within a treatment is met by independent replications in the simulation. ANOVA is robust to departure from normality and variance-homogeneity.

The most important finding of this analysis is the different impact of dealing with the two kinds of resources (beds and chest X-rays) on the technical performance of HSRP.
In the case of chest X-ray resources, we find support for those hypotheses which state that the strategies to deal with uncertainty improve the technical performance (hypothesis 2, 3, 4, 5). Significant interaction effects further learn that these strategies may not be considered separately. For instance a strategy of dynamic order due date maintenance is only meaningful when a planning periodicity of one day (high planning frequency) is used. This is a modification of hypothesis 3.

In the case of bed resources, we do not find any support for the hypotheses 2, 3, 4 and 5. None of the strategies to deal with uncertainty has a positive impact on the technical performance of HSRP when dealing with this kind of length of stay dependent resources. Safety lead-time has a very clear negative impact on the technical performance.

When trying to explain the different behaviour of bed and chest X-ray resources in response to the introduction of different strategies to reduce uncertainty, we refer to their different nature, i.e. the extent to which they are length of stay dependent. Another important factor is probably the selection of an average length of stay as standard lead-time in the bill of resources.

Although each source of uncertainty has individually a negative effect on the technical performance of HSRP, we do not find any support for a multiplicative effect (hypothesis 1). There is no indication that the strategies to deal with uncertainty in the case of chest X-ray resources only have a positive effect when there is limited capacity (hypothesis 6). Only in the case of chest X-ray resources, a classification error has a significant negative impact on the technical performance of HSRP (hypothesis 7).

Conclusion and further research question

The main research contribution of this study can be stated as follows:
As to the technical performance of HSRP, we cannot conclude definitely whether the system is feasible for a hospital environment. The current study has allowed to identify those factors which

are important in determining the technical performance of HSRP: the extent to which resources are length of stay dependent and the way on which one deals with lead-time uncertainty, more specifically variability in the length of stay.
The extent to which resources are length of stay dependent has a double impact on the performance of HSRP:

1. The estimation of the requirements for resources which are length of stay dependent is significantly better than the estimation of the requirements for resources which are not length of stay dependent.

2. The different strategies to deal with uncertainty have a clearly better effect on the accuracy of the estimations of the requirements for resources which are length of stay independent than on the accuracy of the estimations of the requirements for resources which are length of stay dependent.

There are also some managerial implications which are related to the design and the use of a HSRP system in hospitals:

1. The first task in developing a more integrated planning system is to study the capacity structure of the hospital and to classify the resources in more homogeneous groups according to some criteria.

2. The ultimate selection of Diagnosis-Related Groups as product line definition is chiefly based on practicality considerations, but the question is whether practicality considerations will continue to dominate the selection decision when software for other patient classification systems such as Patient Management Categories become generally available at affordable price through a larger diffusion over the world.

3. A hospital must increase its capability to process more information.

4. Attention must be paid to the development of measures of resource use.

Finally, we formulate some further research questions:

1. An investigation of the planning performance of HSRP.

2. The study of other strategies to (further) improve the technical and planning performance of HSRP.

3. The study of other approaches to perform the task of service requirements planning.

4. The generalisation of the findings to other patient groups and departments of the hospital.

5. Questions related to organisational and implementation issues.

6. Software development.

UNIVERSITY OF GENT
Faculty of Economics

A SIMULATION-BASED EXPERIMENTAL INVESTIGATION OF A HOSPITAL SERVICE REQUIREMENTS PLANNING SYSTEM UNDER DIFFERENT SOURCES OF UNCERTAINTY

PART 2: APPENDICES

Dissertation submitted in fulfillment of the degree of
Doctor in Applied Economics

by

Paul GEMMEL

Academic year 1994-1995

Thesis supervisors:

Professor Dr. W. Bruggeman
&
Professor Dr. ir. R. Van Dierdonck

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APPENDIX 1

LIST OF HOSPITALS AND PEOPLE INVOLVED IN A PRELIMINARY STUDY OF THE HOSPITAL PROCESS IN FUNCTION OF PROBLEM STATEMENT AND PROBLEM DEFINITION.

APPENDIX 1 LIST OF HOSPITALS AND PEOPLE INVOLVED IN A PRELIMINARY STUDY OF THE HOSPITAL PROCESS IN FUNCTION OF PROBLEM STATEMENT AND PROBLEM DEFINITION.

The specific objectives of the exploratory study in three American hospitals are the following:

1. Learning about the internal operating system of a hospital, more specifically about how resources are managed within a short-range planning horizon.

2. Investigating how data for our doctoral study can be collected.

A combination of non-structured interviews and observation has been used to obtain the objectives. The exploratory studies have been realized with the support of prof.H.Zuckerman and prof. Kirkmann-Liff, both professors at the Health Care Service Administration program, College of Business, Arizona State University. The following table gives an overview of the three hospitals and the people I have talked to. A total of 18 hours interview have been performed in the period january/march 1993. Appendix 2 shows one of the reports which have been produced as a result of these interviews. This report is representative for the findings in the other hospitals.

ST.JOSEPH'S HOSPITAL AND MEDICAL CENTER

St.Joseph's Hospital and Medical Center, located in Phoenix, is sponsored by the Sisters of Mercy and is a division of Catholic Healthcare West. Today, it has more than 4000 employees and 32.000 patients per year. It is a non-profit institution.
I have interviewed the following people:

T. Finnigan,	Director Resource Utilization Management
C. Pearson,	Clinical Director Radiology Department
G. Barnett,	Director of Laboratory Services
P. Styer,	Director of Materiel Services
P.M.Wekell,	Director of Case Management
P. Dhurstin,	Clinical Director 'Saveday' Surgery
L.B.McMillan	Manager, Clinical Systems

SAMARITAN HEALTH SERVICES/GOOD SAMARITAN REGIONAL MEDICAL CENTER

Samaritan Health Services own and manage 24 hospitals and health-care facilities in several states. It is a non-profit system. Good Samaritan Regional Medical Center is the largest hospital of the System (642 beds) located in central Phoenix. Good Samaritan medical staff numbers 1550 representing 45 different specialties. I have interviewed the following people:

Marie Romano,	Director Management Support Systems
Twila Burdick,	System CQI Coordinator
John Neuner,	Director, Managed Care Data
S.L.Pettigrew,	Resource Evaluation/Mat.Management
Patrick McNamara,	Director Managed Care Program
D.Lampeider,	Assistant Controller Finance
Carla M.Clarck,	Nurse Research Clinician
Joan Brambert,	Implementation Coordinator Patient Care Redesign

SCOTTSDALE MEMORIAL HOSPITAL NORTH

Scottsdale Memorial Hospital North is a 200-bed hospital in Scottsdale, near Phoenix. It is part of Scottsdale Memorial Health Systems, Inc., a not-for-profit health care network.
I have interviewed the following people:

Becky Dalton,	Manager Admitting Department
Stan Prorock,	Manager of Application Development, Information Systems
Scott Balcom,	Financial Analyst
Janet Peterson,	Clinical Director OR scheduling
Joyce Benjamin	Clinical Director Nurse Staffing
Victoria Kullman	Manager Radiology Department
Janet Simmons	Clinical educator, Special Care Center

APPENDIX 2

A REPORT OF THE FINDINGS IN THE PRELIMINARY STUDY IN SCOTTSDALE MEMORIAL HOSPITAL NORTH

APPENDIX 2 A REPORT OF THE FINDINGS IN THE PRELIMINARY STUDY IN SCOTSDALE MEMORIAL HOSPITAL NORTH

PAUL GEMMEL
ICM FELLOW
VISITING SCHOLAR
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THE MANAGEMENT OF RESOURCES IN SCOTTSDALE MEMORIAL HOSPITAL NORTH

1. INTRODUCTION

During a period of three days, I have wandered around in Scottsdale Memorial Hospital North (SMHN). I have interviewed people of several departments : admitting department, information systems department, OR department, nursing department and radiology department.
The main purpose is to study how the resources in the hospital and in each of the departments are managed. There is more emphasis on the analysis of the relationship between departments than on the analysis within the departments.
The results of this research are a couple of observations and recommendations that should be helpful to the resource management of SMHN. Before listing these results, it is important to describe the framework I used in the analysis of this hospital and to define some concepts.

2. FRAMEWORK

I have used a 'system' point of view on a hospital. Basically this means that the hospital is described in terms of input, conversion process and output (Reisman, 1979) or in terms of resources , activity and outcome (Griffith, 1992)

- Figure 2.1. to be inserted here -

Resources are work-force resources, supplies and materials.
In a hospital, beds, nursing capacity, OR capacity, screening and treatment capacity (laboratory and radiology) are frequently indicated as the most important resources (Rhyne, 1988).
Work-force and facility resources have the capability of delivering services. Capacity is then a measure of this capability. The capacity of hospitals to accommodate patients is limited either by the capacity of work-force resources or by the capacity of facility resources (Siferd, 1992).
When the nursing work-force is the limiting factor, this means that filling beds with patients, in excess of the server capacity only leads to increases in the length of stay (LOS).
The outcome is the result of the hospital activity. It is a multi-dimensional concept encompassing output (i.e. the counts of goods and services delivered by service units), efficiency (output per unit of input or resource consumed) and quality (the value of the output on behalf of the customer) (Griffith, 1992).
The conversion process is a sequence of activities that transforms inputs into outcomes.
Because in a hospital, few activities can be performed without a patient physically present or close by, the role of the patient in this model must be clearly reflected (See 'demand' in figure 2.1).

The behaviour of the demand for hospital services is dependent on the arrival pattern of patients. This pattern can be characterised as stationary or cyclic, scheduled or emergency and as deterministic or stochastic (Dowling, 1976).
A stationary demand pattern is essentially the same from day to day. A cyclical demand pattern is one in which the quantity of services sought rises and falls in a recurring systematic manner, usually by day of the week or season. A deterministic demand means that patients arrive at predictable intervals. A stochastic demand means that they arrive at unpredictable intervals with little notice (Griffith, 1992).
Stationary and deterministic demand are consistent and predictable. Demand on any given day is also predictable for cyclical and deterministic demand. These demand patterns are

schedulable. Problems arise with stochastic demand where the demand pattern is unpredictable and which causes the need for standby reserve capacity or excess capacity (Dowling, 1976). It is in this stochastic situation that there exists a fundamental trade-off between cost of excess capacity and costs of not having enough capacity (and not being able to deliver services) (Dowling, 1976).

An important characteristic for service operations management is the high variability in operations (much higher than in most manufacturing settings) (McLaughlin, 1992). The following kinds of variability are generally recognised (McLaughlin, 1992) :

1. Demand variability : uncertainty in daily operations due to variability in arrival times;
2. Product-mix variation : uncertainty in daily operations due to variability in patient requirements;
3. Customisation : customer contact personnel (e.g. nurses, physicians) can exercise considerable judgement in meeting individual customer needs and has executional latitude in delivering the service.
4. Server variability : the availability of work-force resources can be influenced by many different factors such as illness, the current workload, ... One of the big problems in service sectors is that the capacity of work-force and facility resources is perishable i.e. it cannot be held in inventory.

In the literature many different strategies have been described to cope with this variability in the (hospital) process (Siferd, 1992 summarises this literature).
These strategies can be categorised in three broad classes of solutions :

1. Management of the patient flow in and through the hospital by admission and throughput forecasting, planning and/or scheduling.

2. Management of the capacity of resources i.e. making resources flexible or holding excess capacity.

The first category of solutions is focused on 'stability' while the second category is focused on 'flexibility'.

The description of the activity of an individual or groups of individuals in a hospital in terms of the resources required, the work methods and procedures used (process) and the results (outcome) is only possible when specific expectations are set (Griffith, 1992) (See figure 2.1). These expectations are set through an exchange process of the hospital with its environment.

The process of setting and defining expectations in advance is the essence of each planning system. In order to ensure that the expectations are fulfilled, one needs a monitor who compares actual performance to expectations and who takes action when deviations are detected. Monitoring and translating expectations in operational terms are the main functions of the feedback loop in the proposed hospital model.

For the hospital, this feedback loop can be described as in figure 2.2.
The service manager plans future levels of service and resource requirements in conjunction with unit managers. In resource allocation, budget and resources are allocated to service managers to provide a given level of services. Resources are then managed (scheduled or kept flexible) to achieve required service level. The extent to which this level of service provision is reached is monitored. This whole process is supported by information about resource utilisation and about possible future service provision (Kirkman-Liff et al., 1992)

- Figure 2.2. to be inserted here -

To be useful for physicians and managers as an aid to improve effective and efficient use of resources, such information must be 'case' or 'case-mix'- based. This means that a case-mix information system must be in place. Such an information system subsumes : detailed patient data, a system for classifying patients into clinical homogenous groups and a mechanism to generate reports based on the patient data and classification schemes. One of the distinctive features of a case-mix information system is the merging of clinical and financial data. This link is fundamental in the feedback loop of the hospital process taking into account the current case-based reimbursement systems.

3. OBSERVATIONS

We have listed the observations by department (admitting, OR, nursing, radiology and information systems). As a kind of general introduction, we first give the results of some (limited) analysis of census data of the hospital.

3.1. Analysis of the Hospital Census

We have analysed the total number of daily admissions and discharges, and the census from August 1st, 1992 until January 27th, 1993. Figure 3.1 shows respectively the variation of the daily census ([1]), the daily number of admissions and daily number of discharges with the average as a base-line. Table 3.1. shows the mean and standard deviation for each of these variables.

Table 3.1. Mean and standard deviation of the census, the number of admissions and the numberof discharges

	CENSUS	ADMISSIONS	DISCHARGES
SAMPLE SIZE	180	180	180
MEAN	142.9	30.5	30.4
STD.DEVIATION	23.6	12.2	8.7

The plot of the daily census clearly shows the seasonal variation in demand. Each of the plots also shows a substantial daily variation in the variables (census, number of admissions and discharges). To illustrate how large these daily fluctuations sometimes are, we show in table 3.2. the evolution of the variables for some limited periods.

- figure 3.1. to be inserted here -

The daily variation learns that the demand for services in SMHN does not behave as a deterministic demand pattern. The question is whether and how this demand pattern can be made more deterministic.

Table 3.2.

NUMBER OF ADMISSIONS FROM 08/02/92 TO 08/10/92

08/05/92	08/06/92	08/07/92	08/08/92	08/09/92	08/10/92
36	19	36	6	14	37

[1]. This the census on midnight of day x = the previous midnight census + number of admissions - number of discharges.

Table 3.2.(Continued)

NUMBER OF DISCHARGES FROM 08/25/92 TO 08/29/92

08/25/92	08/26/92	08/27/92	08/28/92	08/29/92
26	40	31	53	30

CENSUS FROM 11/10/92 TO 11/19/92

11/10/92	11/11/92	11/12/92	11/13/92	11/14/92
146	152	171	174	154
11/15/92	11/16/92	11/17/92	11/18/92	11/19/92
144	142	151	165	174

Based on these tables and plots, one can certainly conclude that the patient flow in and out the hospital is not controlled.

An analysis per day of the week also reveals some interesting patterns. Figure 3.2. shows a plot of the average daily census for each day of the week.
This figure shows for example that the average daily census on all the Mondays during the period of analysis is 135. Although the samples are too small to do statistical analysis, we can extract some interesting information. Wednesday and Thursday are the busiest days in terms of the number of people in the hospital. The population is mainly built up on Monday and Tuesday, and is built down on Friday and Saturday. There is some recurring systematic demand pattern over a week period. In other words there is some cyclical (i.e.weekly) demand pattern. It is further quite remarkable that on Saturday the average daily census is almost equal to that of Monday. On Friday midnight, there are still a lot of patients in the hospital.

- Figure 3.2. to be inserted here -

Based on these figures, we can make two important observations:

1. The average daily census is low on Monday compared with the other weekdays;
2. On Friday evening, a considerable amount of the patients are still in the hospital.

3.2. The Admitting Department

The preceding analysis of the hospital census reveals that the flows in and out the hospital are not controlled. This kind of control is a task which can be performed by the admitting department. Without any controlling function the admitting department must be able to make capacity (i.e. beds) 'flexible'. This flexibility is indeed present:

1. People of the admitting department do not assign rooms and beds until the day of admission. On this day they only assign a patient to a floor. This gives the nurse on the floor the flexibility to assign a patient to a room, taking into account the availability of nurses. If the floor is in a bed crisis, it is up to the nursing supervisor to decide whether surgeries must be cancelled. This hasn't happened yet. Nursing normally prefers to hold people into recovery rooms until a bed comes free.

2. By admission, surgical patients are going to 2A which is a pre-surgical floor. So a bed is only assigned to patients after they have been operated. When no bed is available (after surgery), the patient can be kept in recovery room (see point (1)).

3. During almost the whole year, there is an excess capacity of beds. In other words, beds are not a constraining resource.

The 'bed controller' plays a very important role in managing the resources in such a flexible way that no 'crises' occur. For instance on the board used through the bed controller, discharges which are pending are indicated as such. This gives the bed-controller the possibility to assign beds to (new) patients who are still in surgery at this moment although the beds are not yet free. Based on the 'noon' schedule of the bed controller, it is also decided whether on-call nurses must be called in.

The whole bed control system is still manual. Admitting does not believe that the system can be automated in the same effective way. In general, the department does not have a lot of confidence in the information system (fear for down-time).

3.3. The Operating Room Department

The OR department plays an important role in determining the average daily census of the hospital. For surgical patients the OR is first scheduled by the surgeon (or his/her secretary). The same surgeon then calls the admitting department to inform admitting of the scheduling date. So the day of admission is dependent on the day of surgery. Nevertheless there is no direct (within hospital) link between the OR schedule and the admission schedule.

For surgical patients the flow into the hospital can be 'controlled' through the OR advance schedule. This also means that the hospital's only constraint, taken into account when scheduling surgical patients, is the OR time.
The estimation of the OR time needed for a certain procedure is thus an important parameter in scheduling ORs. The accuracy of these estimates determines the accuracy of the schedule. In SMHN the procedure time is estimated by the surgeon. The OR scheduler can check this time estimation with a data-item where the historical actual time is kept, i.e. the time the surgeon needed to do this procedure in the past.

The OR advance schedule used is a mix of a block scheduling system and a First Come First Served system. The Mayo physicians have a set of blocks and the community surgeons are served on a first come first served base. It is important to see that the assignment of blocks to certain days is also an important decision parameter. It should be interesting to see whether there was in the past some correlation between the assignments of some blocks to some days and the occupancy of the OR and other resources in the hospital. I couldn't get the data to do such kind of analysis.

The control desk in the OR department plays a very important role in the daily allocating schedule, i.e. the assignment of certain cases to a specific OR and starting time. The main allocating procedures are:

1. minimising OR idle time
2. respecting as much as possible the advance OR schedule, i.e. start the operations on times stated in the advance schedule.

To respect these rules as much as possible, a lot of ad hoc switching between rooms is necessary.

A last observation in the OR department is that the automated OR scheduling system is a stand-alone system; this means that it is not integrated into the Hospital Information System. Nevertheless the OR schedule is a very important document in the hospital. Each day 60 copies of the OR schedule are made and sent throughout the hospital.

3.4. The Nursing Department

Besides the staffing and scheduling rules which are well documented, we have observed that the nursing staff is very flexible even to the point that nurses must be able to adjust on a shift by shift basis. To obtain such flexibility, the following mechanisms are used:

1. overtime; there are some built-in incentives for the nurses to work over time during the weekend.
2. on-call staff.
3. pool or float nurses from outside.
4. the floating of nurses between nursing units; floating is sometimes limited by special skills needed.

These mechanisms have not all the same costs and benefits. Registry nurses are clearly more expensive.

When analysing the staffing pattern from August to December 1992 it becomes clear that only in a few cases registry nurses are hired because there was an absolute shortage of nurses in the hospital. These cases are on 13, 20 and 25 November and 14-16 December. This further means that in all the other cases Registry Nurses are hired because of an imbalance between the mix of nursing skills available and the mix of skills needed. Such a mix is probably as well speciality based as educational based.

Some other observations dealing with the nursing department are:

1. The nursing department perceives itself as being the unit that is the most affected by the high variation in daily census. Nevertheless nursing management has some control over the admissions because they assign patients to rooms. The nursing department has also some control over the time of discharge. Finally nursing feels to have more control over the census because admitting now falls under nursing in the organisational chart.

2. The workload of the nursing department is very much related to the workload of the surgery department. Traditionally the busiest days for nursing are Tuesday, Wednesday and Thursday. These are the days with the highest average daily census. Nursing does not believe that the peak in the workload on these days influences the performance of the nurses because staffing is driven by the census and a patient acuity system.

3. Nurses consider themselves as an important co-ordinator of the different services and resources for a patient. Critical pathways must be seen as a formal tool supporting this co-

ordinating role. Co-ordination means in the first place communication. Critical pathways can improve the communication between different care givers, patient and family.

4. At this moment the collection and analysis of staffing and scheduling data is really inadequate. The installation of a computerised nurse staffing system is urgent.

3.5. The Radiology Department

The radiology department is a service-type department. It encompasses many sub-units (such as general procedures, nuclear medicine, angiography, ...) which run almost completely independently.

Again, the radiology department shows large flexibility in staffing. These flexibility is necessary because of the large variation in the work-load. On each day, there are anywhere from 30% to 150% add-on cases. This means that 30% to 150% more exams are requested on this particular day compared with the morning schedule.
Traditionally Tuesday tends to be the busiest day. Probably this is due to the fact that physicians get their orders placed on Monday for Tuesday (cases from the weekend). It is also interesting to see that on some days (e.g. Friday afternoon) they get more STAT and ASAP requests.

To accommodate this variation in workload, the radiology uses the following mechanisms:

1. staffing flexibility, i.e. for instance the use of part-time work and overtime;
2. prioritising the requests (routine exams, timed exams, STAT exams and ASAP exams);
3. on-call system;
4. outpatient services (outpatient services are used to fill in gaps between inpatient requests).

It is important to note that the variation in workload has an influence on the performance of the department. The turnaround time becomes longer with a heavy load. This longer turnaround time does not necessarily affect the LOS of the patient. This is only the case when there is a pending discharge based on the radiology procedure. There is no impact of a heavier load on the quality level of the services.

The turnaround time has become a much more critical performance parameter in the hospital in the present DRG/PPS environment. Patients are staying in the hospital during a shorter period of time and the same number of tests still need to be done. In other words, more work needs to be done within a shorter period of time. This means that there are much more ASAP and STAT requests today because of DRGs. STAT and ASAP requests are difficult to schedule (predict), and the more cases the radiology department cannot predict, the less reliable are their turnaround times.

Despite these problems, the overall report turnaround time seems to be very good. The department scores less well on another performance measure, i.e. the waiting time for patients before and after procedures. Reduction of the waiting time is difficult because the radiology department does not control all factors contributing to this waiting time.

Although the working of the radiology department is strongly supported by a computerised Radiology Information System (RIS)(that is fully integrated with the Hospital Information System), scheduling and staffing are still done manually. The scheduling module of the current RIS is inadequate. The department is looking for another package.

3.6. The Information System Department

As pointed out in the framework, a case-mix information system is indispensable today to manage the resources of a hospital. Such an information system subsumes the following components.

1. An integrated hospital information system (HIS);
2. A system which is able to collect resource use data on patient level or patient group level;
3. A mechanism to generate reports based on these patient data and classification schemes;
4. A link between financial data and clinical data.

The transformation of the SMHN Hospital Information System since August last year is really one which is completely compatible with an evolution to a case-mix information system. The new system (HBO's Clinstar System) encompasses as well clinical as financial applications. (In the old system, different information systems were used for respectively the financial applications and the clinical applications.)
As to the degree of integration, table 3.3. shows an overview of the different applications in a comprehensive and totally integrated Hospital Information System (HIS) (See Zviran, 1990).

It shows which applications are or will be available in the current HIS of SMHN, which applications are not available and which applications are available but are not integrated into the HIS.
Appendix 1 defines each of the applications.
It is remarkable that the applications necessary to manage the most important resources in a hospital (nurses, laboratory, pharmacy, OR and even radiology - remember that there is no automated scheduling system in radiology) are not yet integrated in the HIS of SMHN. Nonetheless, the information system department is very much aware of the need of connecting departmental computer systems in the hospital into a hospital-wide information network.

The HBO Clinstar System is able to collect very detailed data on patient level and to summarise these data for patient groups (DRGs). Table 3.4. gives an overview of the data-items which reside in a very comprehensive case-mix information system (Lichtig, 1986). It is indicated which data-items reside in the CLINSTAR system.

One important remark is that the DRG grouper, used to classify patients in homogeneous groups is inadequate to be useful for clinicians and operational managers to effectively manage their resources. Some kind of severity adjustment is necessary.

Table 3.3. Application systems and their availability and integration

ACCOUNTING SYSTEMS	AVAILABLE IN THE HIS
FINANCIAL SYSTEMS	AVAILABLE IN THE HIS
INVENTORY MANAGEMENT SYSTEMS	STAND-ALONE
EQUIPMENT MANAGEMENT SYSTEM	STAND-ALONE
GENERAL MANAGEMENT SYSTEMS	PERSONNEL SYSTEM AVAILABLE NURSING STAFFING WILL BE AVAILABLE SOON
PATIENT REGISTRATION	AVAILABLE IN THE HIS
MEDICAL RECORDS	AVAILABLE IN THE HIS
CLINICAL SYSTEMS	SOME EXPERIMENTS WITH REMOTE ACCESS FOR PHYSICIANS
MONITORING SYSTEMS	NOT AVAILABLE IN THE HIS
LABORATORY MANAGEMENT	WILL BE AVAILABLE IN THE HIS SOON
RADIOLOGY MANAGEMENT	AVAILABLE IN THE HIS, BUT NO SCHEDULING MODULE
OR MANAGEMENT	STAND-ALONE
BLOOD BAND MANAGEMENT	PART OF THE LAB SYSTEM
PHARMACY MANAGEMENT	STAND-ALONE SYSTEM

Table 3.4. Data-items residing into the clinstar system

PRESENT IN THE DATABASE	YES	NO
HOSPITAL STAY DATA = describe some key characteristics of an inpatient episode, and the information is generally related to the specific episode		
ADMISSION CERTIFICATION		X
ADMISSION DATE	X	
ADMISSION HOUR	X	
ADMISSION TYPE	X	
ADMITTING NUMBER/ BILLING NUMBER		X
CLINICAL SERVICE	X	
DISCHARGE DATE	X	
DISCHARGE DISPOSITION	X	
DISCHARGE HOUR	X	
LENGTH OF STAY	X	
MEDICAL RECORD NUMBER		X
POSTOPERATIVE LENGTH OF STAY (*)		X
PREOPERATIVE LENGTH OF STAY (*)		X
READMISSION		X
REASONS FOR CANCELLED PROCEDURE	X	
REFERRAL SOURCE TYPE	X	
SURGERY HOUR		X
CLINICAL DATA = describe medical characteristics of a patient's stay, such as patient's reason for admission and any diagnostic or therapeutic procedures performed.		
ADMITTING DIAGNOSIS	X	
BIRTH WEIGHT (*)		X
BLOOD FURNISHED	X	
PRINCIPAL DIAGNOSIS	X	
PRINCIPAL PROCEDURE	X	
PROCEDURE DATE	X	
SECONDARY DIAGNOSIS	X	
SECONDARY PROCEDURES	X	
DIAGNOSIS RELATED GROUPS.	X	

(*) Is not directly available in the database but can be calculated or computed.

PRESENT IN THE DATABASE	YES	NO
PHYSICIAN DATA **= physician identification and clinical speciality**		
PHYSICIAN IDENTIFICATION	X	
PHYSICIAN SPECIALITY	X	
BILLING DATA **= identification and quantification of the type and amounts of resources consumed during an episode of care**		
ACCOMMODATION CHARGES		X
ACCOMMODATION CODE	X	
ACCOMMODATION DAYS	X	
ANCILLARY SERVICE CHARGES	X	
ANCILLARY SERVICE CODE		X
RELATIVE VALUE UNITS		X
PATIENT DESCRIPTION DATA **= provide information about some general patient characteristics that exist without reference to any specific hospital or hospital stay (e.g. age, sex, date of birth...)**	X	
EMPLOYER DATA **= to report employee case mix patterns to employers**	X	

The CLINSTAR SYSTEM also has the full capability to generate all different kinds of case-mix reports (such as for example a report describing LOS statistics by DRG and a report showing the cost per DRG by department). Nevertheless the department is still really young in generating and using these data reports. They are still primarily used in the administrative area of the hospital (and not so often in the clinical area).

Although the CLINSTAR system seems to have the full capability of a case-mix information system, there is still a long way to go to use this capability. For instance, a case-mix information system is able to support a case-based budgeting process. Budgeting in SMHN is still on a departmental base. The unit of analysis is not the case, but patient days.

4. RECOMMENDATIONS

In the theoretical framework, I have described two strategies to deal with variation in the production process of a hospital :

managing the flow of patients through planning and scheduling; managing the capacity of the resources (flexibility).

These two strategies are the extreme end-points of a continuum on which points indicate a mix of both strategies.

Based on the previous observation, SMHN clearly follows a 'flexibility' strategy. The hospital does not try to 'manage' the patient flow in, through and out of the hospital system.

One of the most clear symptoms of this lack of scheduling and planning efforts is the low priority which is assigned to the computerisation of the scheduling and staffing control systems in the different departments I have visited. Although one must be aware that the patient flow cannot be totally controlled, some better control can reduce the daily fluctuation of workload.

One of the starting points to accomplish such a better control is the OR schedule. The assignment of blocks of operation time to certain (Mayo) specialists must be carefully done. The types of cases scheduled for each day must be controlled as much as possible. By altering the types of patients scheduled each day, it is possible to change both occupancy levels and OR utilisation, even if the same number of patients is scheduled.

Another suggestion is trying to shift some of the OR load from the Friday to the Monday. Probably this will result in an (average) lower hospital census on Friday evening.

The choice for flexibility is largely based on the awareness that flexibility is necessary from a customer point of view (where the customer is in the first place the physician). A mechanism that would dramatically decrease the daily fluctuations in hospital census is the so-called 'call-in system' (some elective patients are put on a waiting list and called in based on the load of the hospital), but this mechanism is not customer-friendly.

The admitting department has to take a more pro-active role in controlling the work-flow. The first step is to establish a closer and more direct link between the OR schedule and the admission schedule. The only way to do this is to connect the stand-alone OR scheduling system with the HIS. This would also avoid the time-intensive diffusion of 60 copies of the OR schedule per day. It is further the task of the admitting department to analyse several data-items (e.g. number of admissions, discharges, census) and to detect patterns in these data.

In the nursing department, I suggest to better analyse the mismatch between demand and supply of nursing skills.
The introduction of RES-Q RN will make such analysis possible. It also makes the development of more precise staffing plans possible. The implementation of Res-Q RN will bring many changes in the way data are captured and analysed.
I strongly support the idea of introducing critical pathways in the hospital. They are a way to reduce some variation in the clinical process. This could also be very helpful for the clinical support services such as radiology. The Clinstar system has an analytical tool that is called "critical path" that can help define a critical pathway.

In the radiology department, it is important to computerise the scheduling system as soon as possible. This could be helpful in reducing the waiting-time. When selecting a scheduling system, it is important to consider the possibility to connect the system with the existing RIS. Another point is that admission information can be helpful for the radiology department, only if there exists a correlation between the number of admissions and radiographic procedures requested.

The information system department is still in an infant stage in merging clinical and financial data. The financial services still drive the documentation of the clinical services, while in the future model of information system, the clinical services drive the financial documentation. To make clinical data useful for resource management, severity adjustment is a condition sine qua non. Furthermore, only severity adjusted data are useful for benchmarking, i.e. when the resource utilisation pattern of SMHN is compared to the pattern of other comparable hospitals. There are some companies on the market who clean up the case-mix data, add a severity adjustment and use a very large database for comparison. Such kind of benchmarking will become a very crucial point in the resource management of the hospital.
The capability of the case-mix information system will only be exploited in its totality when 'case-mix management' philosophy is adopted by the hospital managers. This means for instance an evolution from a departmental budgeting and cost-accounting system to a case(-mix) based budgeting and cost-accounting system.

Rigorous data-analysis of some variables (admission, discharge, census, average LOS, workload of different departments and the interrelation between these variables) over some long(er) period of time, using statistical tools, can reveal some interesting patterns in these variables, which can be helpful to better control the flow of patients. I have started some of these data-analyses. Nevertheless, the period of time (August 1st - January 27th 1993) is too short to do rigorous analysis. It would be very interesting to expand this kind of analysis to a broader database.

Figure 2.1. The hospital system: a cybernetic model

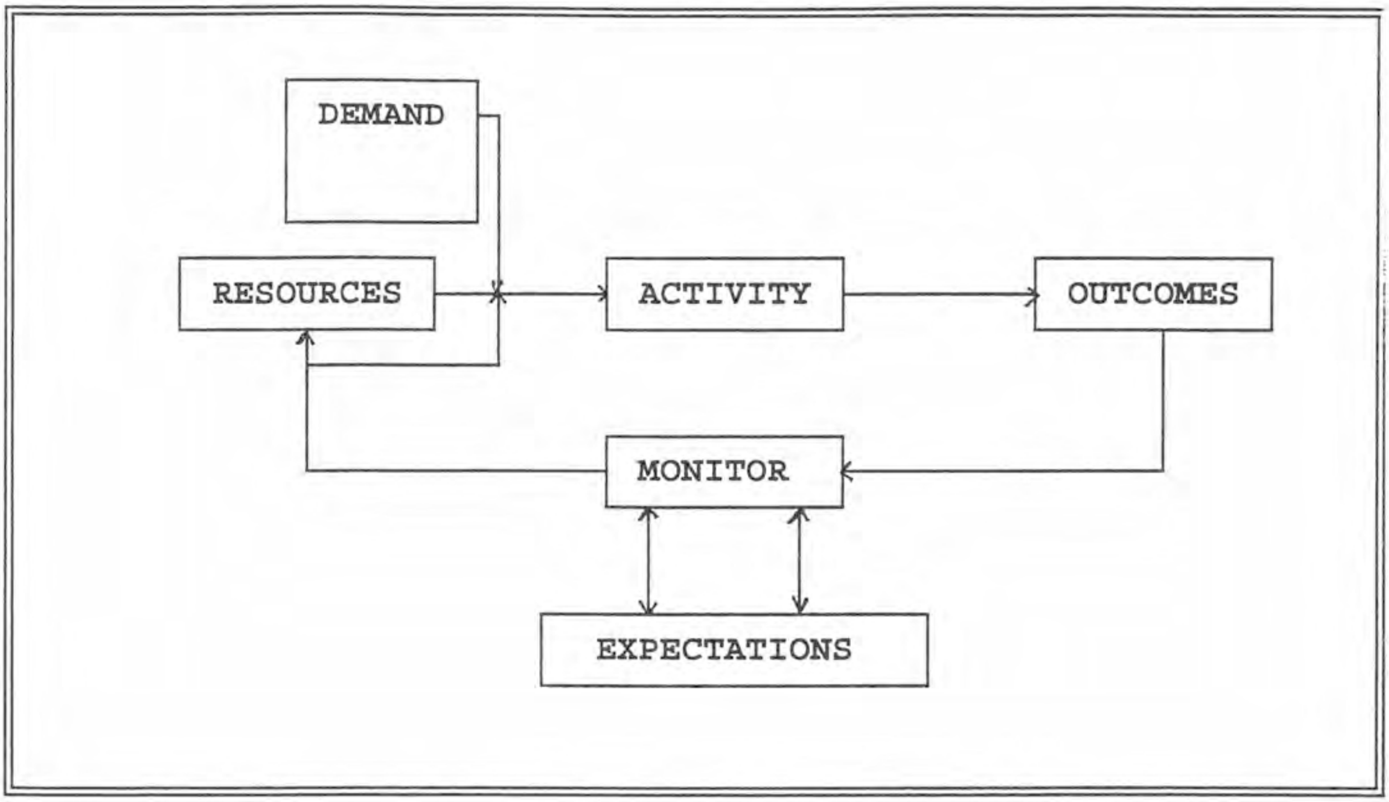


Figure 2.2. The resource management process

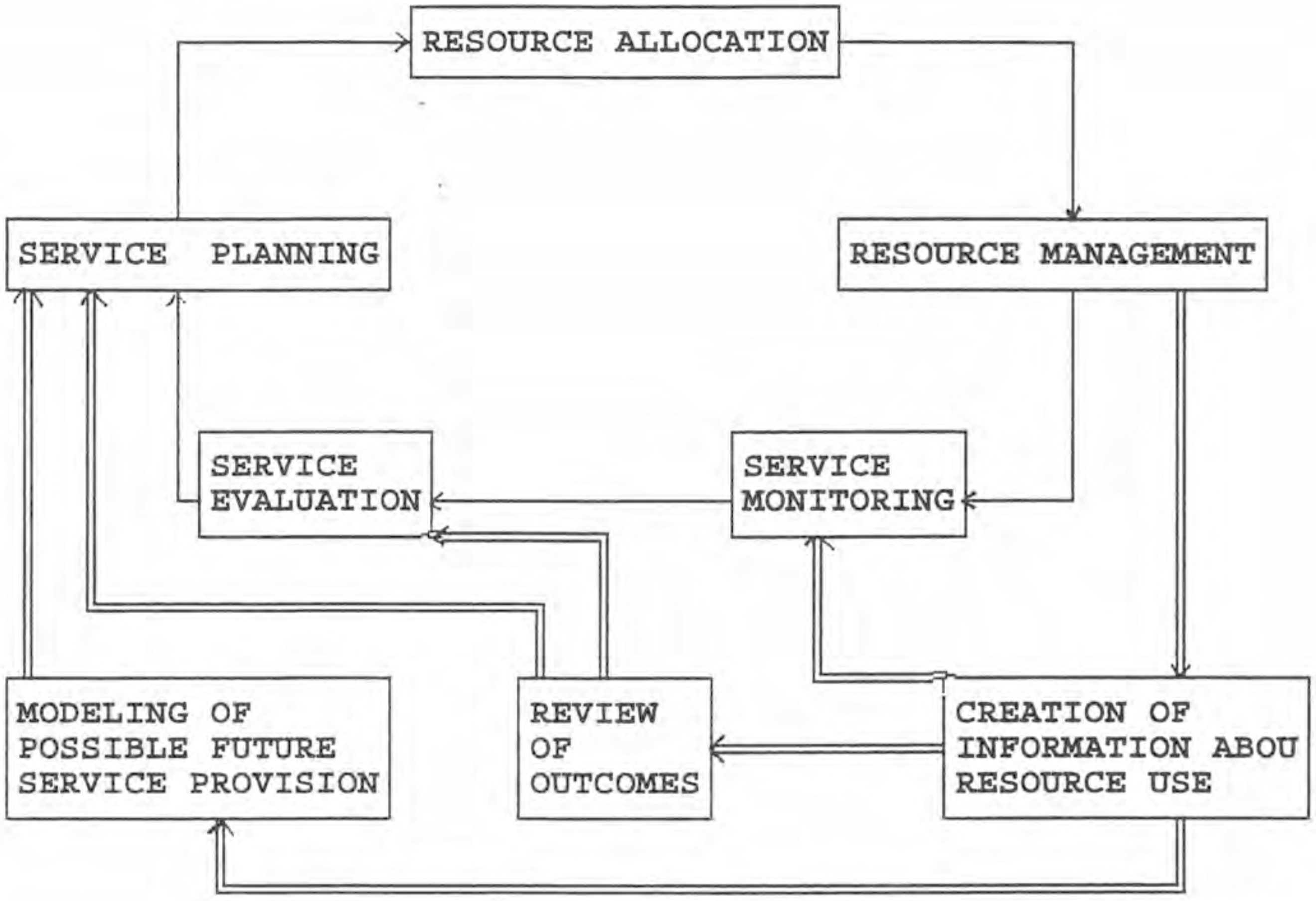
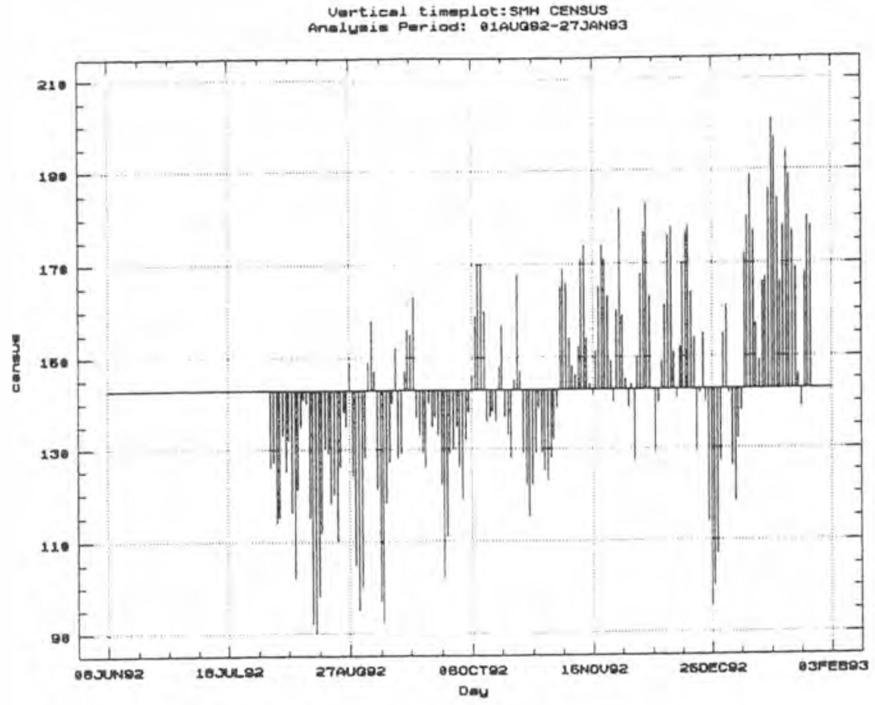


Figure 3.1. The variation of the daily census, the daily number of admissions and daily number of discharges with the average as a base-line



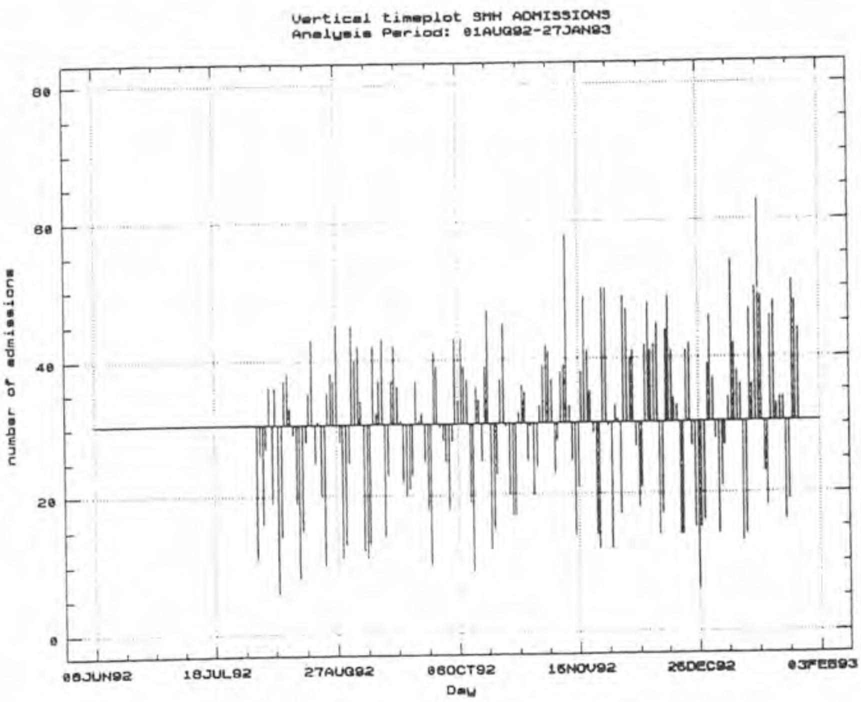


Figure 3.1.(continued) The variation of the daily census, the daily number of admissions and daily number of discharges with the average as a base-line

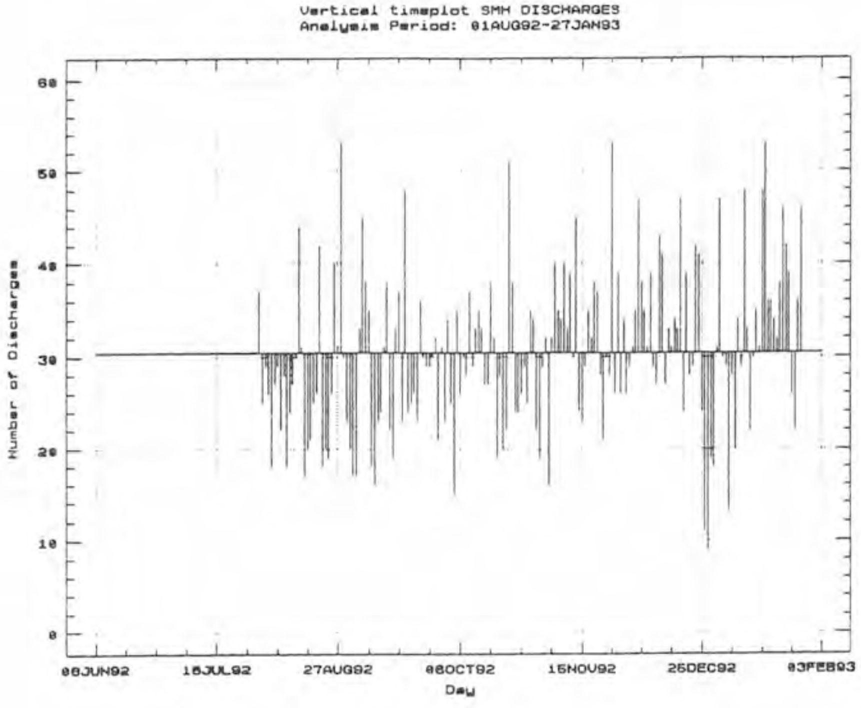
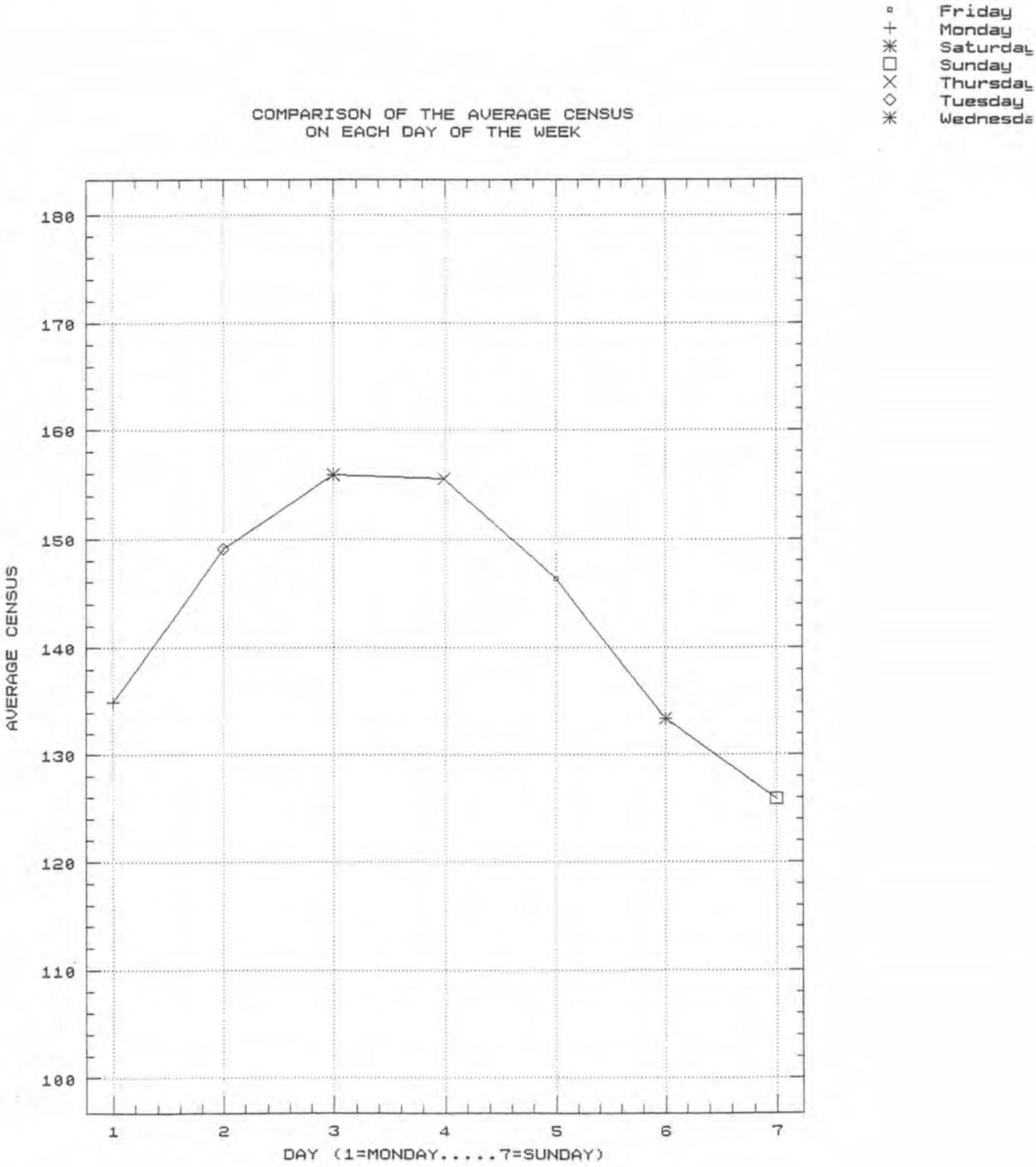


Figure 3.2. The average daily census for each day of the week



APPENDIX 1 **APPLICATION PORTFOLIO FOR AN INTEGRATED HOSPITAL INFORMATION SYSTEM**

ACCOUNTING SYSTEMS: billing and accounts receivable (inpatient and outpatient), accounts payable, general ledger, payroll.

FINANCIAL SYSTEMS: financial planning, budgeting, cost control, pricing, funds and investment management

INVENTORY MANAGEMENT SYSTEMS: inventory control, vendor list, stock/reorder level, automatic substitutions, inactive stock

EQUIPMENT MANAGEMENT SYSTEM: equipment location, maintenance management, depreciation, utilisation analysis, replacement flags.

GENERAL MANAGEMENT SYSTEMS: systems to support personnel management, staffing, staff scheduling, project management, resource control.

PATIENT REGISTRATION: admit, transfer, and discharge system (ATD), appointments and hospitalisation scheduling

MEDICAL RECORDS: systems for managing coded diagnoses (using for example the ICD-9 classification and a link to the patient record.

CLINICAL SYSTEMS: computerised nursing stations and doctor's offices, doctor's orders and treatment plan management

MONITORING SYSTEM: applications to support a direct link from monitoring systems (e.g. ECG, EEG) to a nursing station and automatic updating of patient records).

LABORATORY MANAGEMENT: systems to process the orders for laboratory tests, schedule tests and report results. These applications may be hooked to various laboratory instruments for automatic transfer of results.

RADIOLOGY MANAGEMENT: order processing, scheduling and reporting of results from radiology facilities (e.g. X-ray, C.T., radiology therapy).

OPERATING ROOM MANAGEMENT: application to provide better use of operating rooms through scheduling and planning.

BLOOD BANK MANAGEMENT: inventory control of blood stock, potential donors database.

PHARMACY MANAGEMENT: management and inventory control of drugs and medications, vendor list, stock/reorder level and automatic substitutions.

APPENDIX 3

THE CATEGORIES OF ICD-9-CM CODES

APPENDIX 3 ICD-9-CM = THE INTERNATIONAL CLASSIFICATION OF DISEASES, NINTH REVISION, CLINICAL MODIFICATION

The International Classification of Diseases, ICD, is an official list of diseases and disorders developed by the World Health Organisation, an agency of the United Nations. The ICD was developed primarily for coding morbidity and mortality data for statistical purposes. The current version of the list, the ninth revision, has been modified for use in the United States and is called ICD-9-CM: International Classification of Diseases, Ninth Revision, Clinical Modification. The clinical modifications were made to the international codes so that the coding system could serve as a useful tool in the area of classification of morbidity data for indexing of medical records, medical care review, and ambulatory and other medical care programs, as well as for basic health statistics. (Lichtig, 1986, pp. 99-102). In the following tables we list as an example the categories of ICD-9-CM Codes.

Table The Categories of ICD-9-CM Diagnosis Codes and of ICD-9-CM Procedure Codes (Lichtig, 1986, pp.100-101)

Code Range	Diagnosis Category
001-139	Infectious and Parasitic Diseases
140-239	Neoplasms
240-279	Endocrine, Nutritional, and Metabolic Diseases and Immunity Disorders
280-289	Diseases of the Blood and Blood-Forming Organs
290-319	Mental Disorders
320-389	Diseases of the Nervous System and Sense Organs
390-459	Diseases of the Circulatory System
460-519	Diseases of the Respiratory System
520-579	Diseases of the Digestive System
580-629	Diseases of the Genitourinary System
630-676	Complications of Pregnancy, Childbirth, and the Puerperium
680-709	Diseases of the Skin and Subcutaneous Tissue
710-739	Diseases of the Musculoskeletal System and Connective Tissue
740-759	Congenital Anomalies
760-779	Certain Conditions Originating in the Perinatal Period
780-799	Symptoms, Signs, and Ill-Defined Conditions
800-999	Injury and Poisoning
V01-V82	Factors Influencing Health Status and Contact with Health Service
E800-E999	External Causes of Injury and Poisoning

*U.S. Department of Health and Human Services Public Health Service, 1980.

Table (continued) The Categories of ICD-9-CM Diagnosis Codes and of ICD-9-CM Procedure Codes (Lichtig, 1986, pp.100-101)

Code Range	Procedure Category
01-05	Operations on the Nervous System
06-07	Operations on the Endocrine System
08-16	Operations on the Eye
18-20	Operations on the Ear
21-29	Operations on the Nose, Mouth, and Pharynx
30-34	Operations on the Respiratory System
35-39	Operations on the Cardiovascular System
40-41	Operations on the Hemic and Lymphatic System
42-54	Operations on the Digestive System
55-59	Operations on the Urinary System
60-64	Operations on the Male Genital Organs
65-71	Operations on the Female Genital Organs
72-75	Obstetrical Procedures
76-84	Operations on the Musculoskeletal System
85-86	Operations on the Integumentary System
87-99	Miscellaneous Diagnostic and Therapeutic Procedures

*U.S. Department of Health and Human Services Public Health Service, 1980.

APPENDIX 4

THE MAJOR DIAGNOSTIC CATEGORIES (MDCs)

APPENDIX 4 THE MAJOR DIAGNOSTIC CATEGORIES (MDCs)

The MDCs were formed by physician panels as the first step toward insuring that the DRGs would be clinically coherent. The diagnoses in each MDC correspond to a single organ system or aetiology and in general are associated with a particular medical speciality.

Table The Major Diagnostic Categories (MDCs) (source: Fetter (eds.), 1991, p.33)

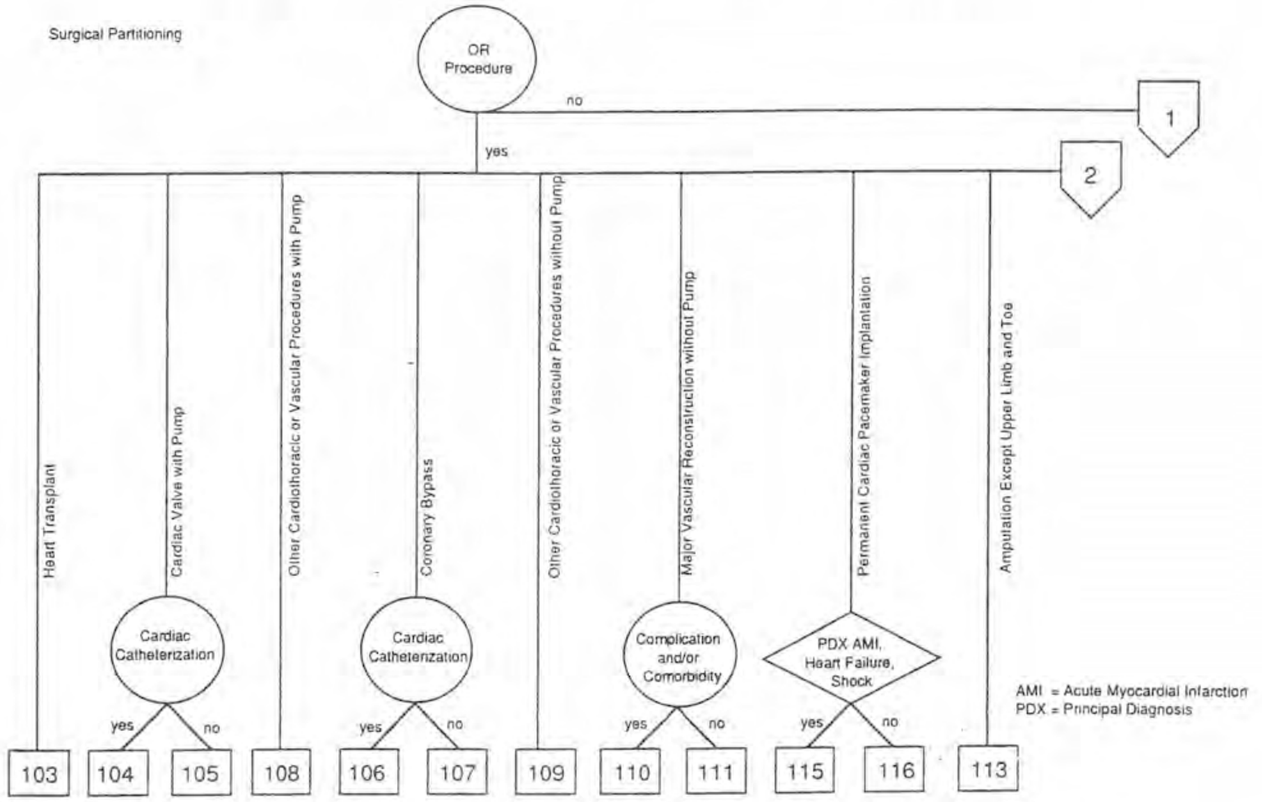
1. Diseases and disorders of the nervous system
2. Diseases and disorders of the eye
3. Diseases and disorders of the ear, nose, and throat
4. Diseases and disorders of the respiratory system
5. Diseases and disorders of the circulatory system
6. Diseases and disorders of the digestive system
7. Diseases and disorders of the hepatobiliiary system and pancreas
8. Diseases and disorders of the musculoskeletal system and connective tissue
9. Diseases and disorders of the skin, subcutaneous tissue, and breast
10. Endocrine, nutritional, and metabolic diseases and disorders
11. Diseases and disorders of the kidney and urinary tract
12. Diseases and disorders of the male reproductive system
13. Diseases and disorders of the female reproductive system
14. Pregnancy, childbirth, and the puerperium
15. Newborns and other neonates with conditions originating in the perinatal period
16. Diseases and disorders of blood and blood forming organs and immunological disorders
17. Myeloproliferative diseases and disorders, and poorly differentiated neoplasms
18. Infectious and parasitic diseases (systemic or unspecified sites)
19. Mental diseases and disorders
20. Alcohol/drug use and alcohol/drug-induced organic mental disorders
21. Injuries, poisonings, and toxic effects of drugs
22. Burns
23. Factors influencing health status and other contacts with health services

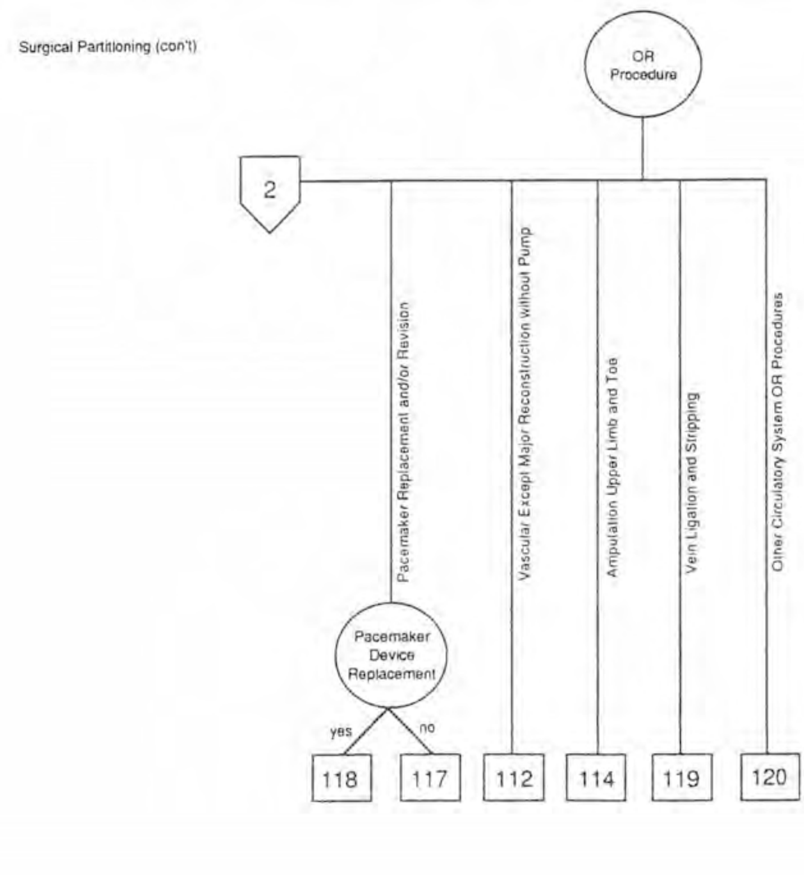
Source: Robert B. Fetter, "The New ICD-9-CM Diagnosis-Related Groups Classification Scheme."

APPENDIX 5

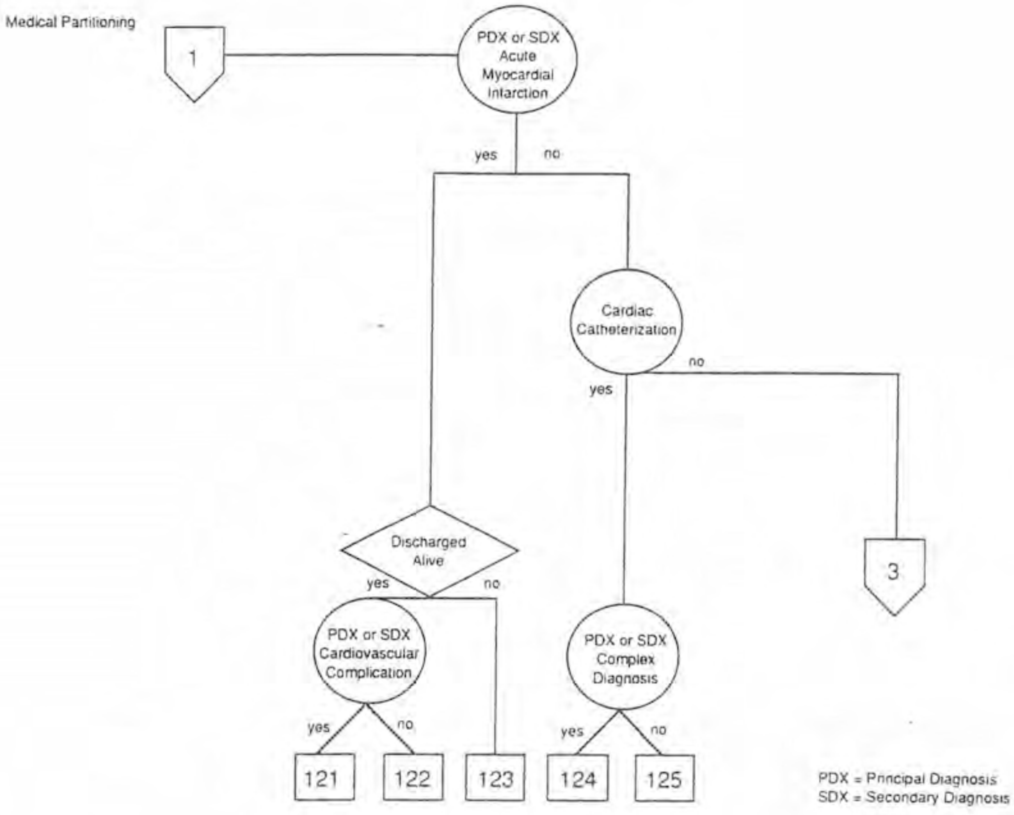
THE TREE DIAGRAM OF THE MDC 5

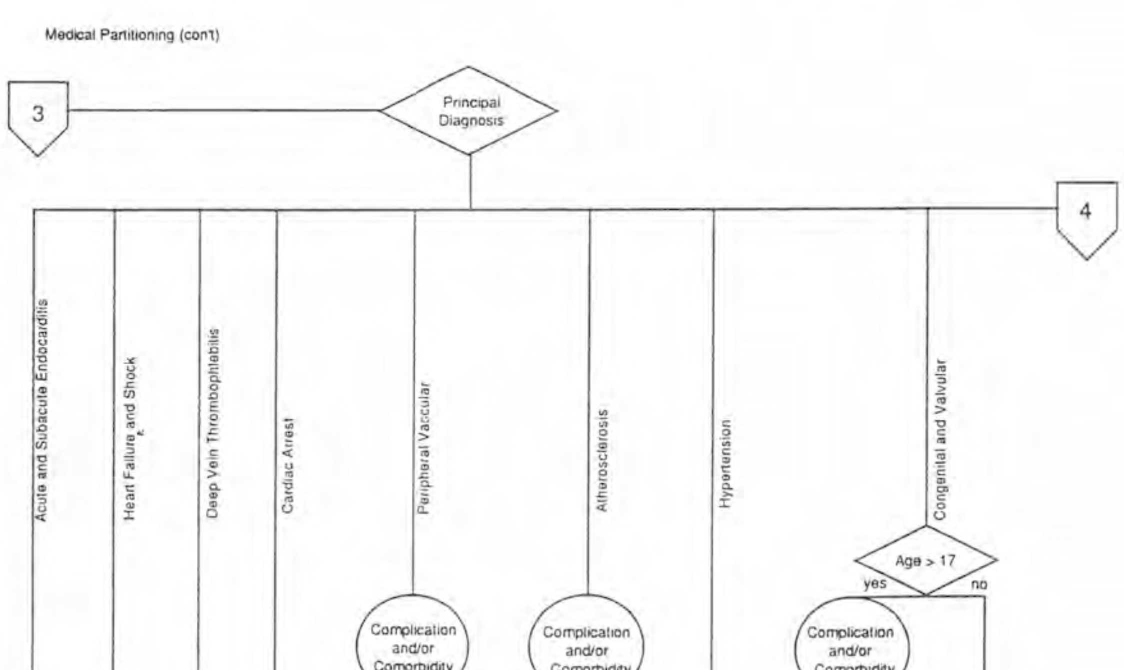
APPENDIX 5 THE TREE DIAGRAM OF MDC 5 - DISEASES AND DISORDERS OF THE CIRCULATORY SYSTEM (source Fetter, eds., 1991, pp. 16-20).



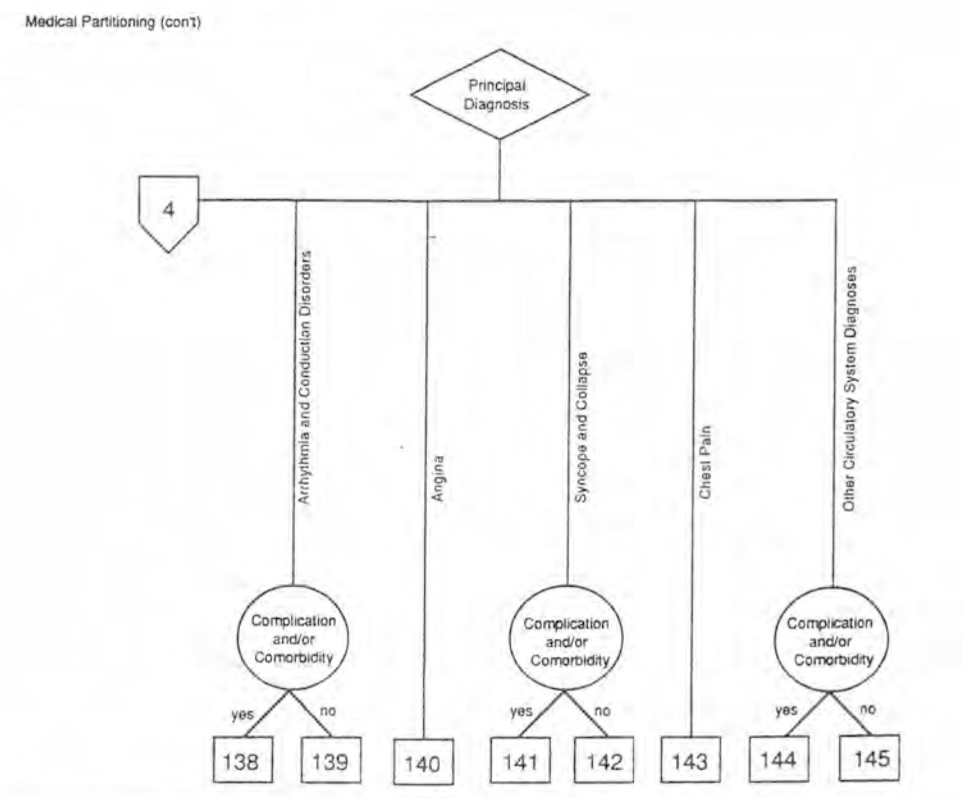


APPENDIX 5 The tree diagram of MDC 5 (continued)





APPENDIX 5 The tree diagram of MDC 5 (continued)



Source: *DRG Definitions Manual*, Fourth Revision (New Haven, CT: Health Systems International, 1987).

APPENDIX 6

THE IN-DEPTH CASE STUDY OF THE SERVICE DELIVERY PROCESS OF A CARDIAC SURGERY UNIT IN A UNIVERSITY HOSPITAL IN BELGIUM

APPENDIX 6 THE IN-DEPTH CASE STUDY OF THE SERVICE DELIVERY PROCESS OF A CARDIAC SURGERY UNIT IN A UNIVERSITY HOSPITAL IN BELGIUM

1. Keuze van werkdomein

Algemeen kiezen we voor onderzoek in een '**coronary care' faciliteit (coronaire zorgfaciliteit).** Deze faciliteit omvat deze diensten die enkel bezocht worden door patiënten met aandoeningen die hartbewaking vereisen. Deze patiënten vallen onder MDC 5 (MDC 5 = ziekten en aandoeningen van het hart- en bloedvatenstelsel). Tabel 1.1. geeft een overzicht van de categorieën die onder MDC 5 vallen (volgens het ICD-9-CM systeem).

TABEL 1.1. DE ICD-9-CM DIAGNOSE CATEGORIEËN VOOR MDC 5 (MIG,1993)

ICD-9 categorie	Omschrijving
390 - 392	Acuut gewrichtsreuma
393 - 398	Chronische reumatische hartaandoeningen
401 - 405	Hypertensie
410 - 414	Ischemische hartaandoeningen
415 - 417	Ziekten van de longcirculatie
420 - 429	Overige hartaandoeningen
430 - 438	Cerebrovasculaire aandoeningen
440 - 448	Ziekten van arteriën, arteriolen, en capillairen
451 - 459	Ziekten van venen en lymfewegen en overige ziekten van de bloedsomploop

Een verdere aflijning kan plaatsvinden door enkel het hartstelsel in beschouwing te nemen, en nog meer specifiek de ischemische hartaandoeningen en de overige hartaandoeningen te beschouwen. Onderzoek ([2]) heeft bewezen dat in België algemeen deze twee categorieën de meeste verblijven omvatten voor wat betreft de hartaandoeningen. Onder de ischemische hartaandoeningen vallen: myocard infarcten (acuut, chronisch, oud), angor en aneurysma; onder overige aandoeningen vallen klepaandoeningen, ritmestoornissen, pericarditis, myocarditis, endocarditis, cardiomyopathy, en hartdecompensatie.

We beperken onze doelgroep verder tot de chirurgische ingrepen. Hier moeten we vooral kijken naar de categorie 35-39 heelkunde van het cardiovasculair stelsel.

[2]. Zie Van Loock e.a. "Hospitalisatie voor cardiovasculaire aandoeningen in België", in Nieuws over Ziekenhuis Registratie Systemen, nr.4, 1992.

De 'coronary care' faciliteit is een verzorgingsfaciliteit met een progressie in de doorstroming van patiënten. "Progressie" betekent dat de verandering in de gezondheidstoestand van de patiënt gepaard gaat met een fysisch transfer van de patiënt van de ene dienst naar de andere. Een verblijf in één bepaalde dienst wordt voortaan een stadium genoemd in het ziekteverloop. In de literatuur worden de volgende stadia voor een coronaire zorgfaciliteit onderscheiden: 'coronary care, post-coronary care, intensive care, surgery, ambulatory care'.

2. Keuze van model

Het is de bedoeling de patiëntenstromen doorheen de verschillende diensten (stadia) te modelleren en te simuleren. Hoewel de datacollectie gebeurt op het niveau van de individuele patiënt, is het noodzakelijk groepen van patiënten met gelijkaardige stromen te herkennen. Het modelleren van de patiëntenstromen steunt op twee soorten van gegevens:

1. **de volgorde van de locaties** (diensten) die de individuele patiënten doorlopen. bv. een patiënt met hartinfarct kan opgenomen worden via de spoedopname, daarna naar de intensieve zorgen gaan, dan terechtkomen op de hospitalisatie hart- en vaatziekten en vervolgens geopereerd worden . Het is ook belangrijk de bestemming van de patiënt na ontslag uit het ziekenhuis in beschouwing te nemen.
2. **de verblijfsduur van iedere patiënt op iedere locatie** (dienst).

Met andere woorden, het is de bedoeling om de coronaire zorgfaciliteit te modelleren als een stochastisch netwerk van diensten waar doorheen patiënten stromen op verschillende wijze naargelang van hun ziektebeelden. Om tot deze doelstelling te komen, moeten we verschillende stappen doorlopen:

1. Beschrijven van de populatie van patiënten die terechtkomen in de faciliteit;
2. Beschrijven van het aankomstproces en van de transfertstromen (routings);
3. Beschrijven van het middelenbeslag op elke dienst (locatie).

Voor elk van deze stappen beschrijven we de benodigde data-input en de datacollectie strategie.

2.1. BESCHRIJVEN VAN DE POPULATIE VAN PATIENTEN DIE TERECHTKOMEN IN DE FACILITEIT

Data-input

Voor deze procedure moet men over de volgende gegevens beschikken:

- bestaande en/of gebruikte patiëntclassifcatie
- een aantal demografische factoren zoals leeftijd, socio-economische status en medische historiek

- de medische procedures die uitgevoerd zijn tijdens het verblijf van de patiënt
- andere factoren (zoals risicograad) die van belang zijn voor de stroming van de patiënt doorheen de faciliteit en voor middelenbeslag.

Datacollectie strategie

- Observatie van het systeem
- Meningen van experts werkzaam in het systeem
- Het medisch dossier

2.2. BESCHRIJVEN VAN HET AANKOMSTPROCES EN VAN DE TRANSFERTSTROMEN

Modellen van patiëntenstromen veronderstellen meestal dat de externe aankomsten een Poisson-distributie volgen of met andere woorden dat de tijden tussen opeenvolgende aankomsten een (negatieve) exponentiële distributie volgen. Dit is echter een veronderstelling die getest moet worden.
Over het algemeen is het nodig hierbij een onderscheid te maken tussen niet-geplande aankomsten en wel geplande aankomsten. Enkel de niet-geplande aankomsten zullen een Poisson distributie volgen. Voor de geplande opnames zal ofwel een andere theoretische distributie moeten genomen worden, ofwel moet de empirische distributie gebruikt worden.

De data-input en mogelijke datacollectiestrategieën voor het aankomstproces zijn dan:

Data-input

. de tijd waarop en de locatie (dienst) waar patiënten aankomen; onderverdeeld naar geplande en niet-geplande patiënten. De bedoeling is een ' cumulative probability distribution function' te verkrijgen voor aankomsttijden.

Datacollectie strategie

. centrale opname-administratie

. een speciale studie van het aankomstpatroon van de patiëntengroepen die opgenomen zijn in het onderzoek.

Voor het modelleren van de interne transfertstromen hebben we de volgende data-input en data-collectiestrategie opgesteld:

Data-input

. de locaties waar de patiënten verblijven

. de verblijfsduur in elke locatie

. kennis nemen van de capaciteiten van elke dienst (locatie)

. analyse van capaciteitsbezetting van elke dienst en van de factoren die de capaciteit beperken

Datacollectie strategie

. de centrale opname-administratie of een admission-discharge-transfer-systeem (ADT systeem)

. Elke dienst zal inzicht hebben in de bezettingsgraad over de tijd heen. Idealiter worden deze gegevens centraal bijgehouden (centrale opname-administratie)

2.3 BESCHRIJVEN VAN HET MIDDELENBESLAG OP ELKE DIENST

Data-input

. de parameters van de verdeling van de verblijfsduur van patiënten op een bepaalde locatie. Hiervoor moet een distributie opgemaakt worden die de verblijfsduur beschrijft in ieder van de stadia (diensten) van het proces. Men kan gebruik maken van de empirische distributie of men kan proberen een theoretische distributie te passen op de empirische.

. het middelenverbruik (bv. aantal verpleeguren, operatiekamer-uren, aantal radiologietesten [eventueel in relative value units],....)

. variabelen die het middelenverbruik blijken te bepalen. Dit kan verschillend zijn voor iedere locatie.

Datacollectie strategie

De belangrijkste gegevensbronnen zijn:

. het medisch dossier

. MVG/MKG gegevens

. Facturatiegegevens

. detailplanningssystemen

. meningen van experts

. observatie van het systeem

3. Data-items en datacollectie strategieën

Tabel 3.1. toont de verschillende data-items die moeten verzameld worden. Er wordt aangegeven wat de analyse-eenheid is voor elk van de gegevens. Merk op dat bepaalde gegevens zowel op het niveau van individuele patiënten, op het niveau van DRGs, als op het niveau van diensten moeten verzameld worden.

Tabel 3.2. vat de verschillende datacollectie strategieën voor deze studie samen.

TABEL 3.1. GEGEVENS EN EENHEID VAN ANALYSE

GEGEVENS	DRG	PATIËNT	DIENST
Datum en uur waarop de patiënt wordt opgenomen		X	
De dienst of eenheid waar de patiënt initieel is opgenomen		X	X
Datum en uur waarop de patiënt uit het ziekenhuis wordt ontslagen		X	
De bestemming van de patiënt na ontslag		X	
De DRG-classificatie van de patiënt		X	
Het middelenverbruik van deze patiënten voor de gehele verblijfsduur en dit voor kritische resources	X	X	
Bepalen wat de 'kritische resources' zijn	X		X
De diensten (locaties) waar de patiënten verblijven, meer bepaald de volgorde der locaties	X	X	
Datum en uur waarop de patiënt in elke dienst aankomt	X	X	X
Het middelenverbruik in elke dienst of locatie. Geen beperking tot kritische middelen.	X	X	X
Definiëren van welke 'resources' in elke dienst in beschouwing moeten genomen worden			X
De capaciteit en bezettingsgraad van elke dienst of locatie en de factoren die de bezetting bepalen			X
Variabelen zoals geslacht, leeftijd, socio-economische status, medische historiek, reden voor opname, opnamediagnose, risicograad, en andere factoren die het middelenverbruik en/of de doorstroming van patiënten kunnen beïnvloeden.		X	
De medische procedures uitgevoerd tijdens het verblijf van de patiënten		X	
Nagaan wat de gebruikte patiëntclassificatie is		X	
Geplande en niet-geplande patiënten (spoedopnames)		X	

TABEL 3.2 DATACOLLECTIE STRATEGIEËN

DATACOLLECTIE STRATEGIEËN
1. Consultatie van primaire gegevensbronnen: het medisch dossier
2. Consultatie van secundaire gegevensbronnen zoals: (a) Centrale opname-administratie (b) Minimale Klinische Gegevens (c) Minimale Verpleegkundige Gegevens (d) Facturatiegegevens of Minimale Financiële Gegevens (e) Operatie planning systemen (f) Verpleegkundige staffing systemen (g) Boekhoudkundige gegevens (h) Andere (bv. detailplanningssystemen)
3. Observatie van de patiëntenstromen en van de diensten betrokken in het onderzoek
4. Interviews met de experts in het systeem
5. Delphi techniek
6. Admission/Discharge/Transfer (ADT) systeem

Het medisch dossier is in feite het hart van elk klinisch informatiesysteem. Wanneer de patiënt zich in het ziekenhuis bevindt, noteren geneesheren en verpleegkundigen klinische en andere informatie in dit dossier. Normaliter moeten de meeste van de gewenste gegevens (behalve het specifiek middelenverbruik) kunnen gehaald worden uit het medisch dossier. Het probleem met het medisch dossier is dat het een confidentiële status heeft en dat het voor een niet-geneesheer moeilijk te begrijpen is.

De M.K.G. registratie (Minimale Klinische Gegevens)([3]) geeft een samenvatting van de **pathologie** en **therapiegegevens** van **gehospitaliseerde** patiënten. Vanaf 1 oktober 1990 werd de MKG registratie verplicht voor alle algemene niet-psychiatrische ziekenhuizen (KB 21 juni 1990). Het Ministerie van Volksgezondheid beoogde met de MKG een polyvalent instrument aan te bieden dat kan bijdragen tot zowel het intern beheer van het ziekenhuis als het extern beleid in het algemeen. Het is verder de bedoeling van de Minister op een betrouwbare wijze te komen tot een voor de gehele ziekenhuissector veralgemeende informatie over elke ziekenhuisopname. De MKG registratie maakt het ook mogelijk om de pathologiestructuur van patiëntenpopulaties in ziekenhuizen te beschrijven.

[3]. Bespreking op basis van verschillende brochures van het Ministerie van Volksgezondheid en Leefmilieu (1990, 1991, 1992).

De registratie gebeurt per semester. Elk ziekenhuis heeft de vrije keuze wat betreft de eenheid van registratie: het kan kiezen voor een registratie per ziekenhuisverblijf of voor een registratie per verblijf in een medisch specialisme. Een verblijf moet op zijn minst 24 uur bedragen. Tabel 3.3 geeft een overzicht van de diverse data-items die verzameld worden in de MKG-registratie.

TABEL 3.3. MKG DATA-ITEMS

Minimale Klinische Gegevens	patiëntidentificatienummer
	Geboortedatum
	geslacht (?)
	postcode vanwaar de patiënt woont
	ziekenhuisidentificatienummer
	nummer van de eenheid waar de patiënt is opgenomen; medisch specialisme binnen die eenheid
	Beddenindex (de erkenningsletter van het bed waarin de patiënt fysisch ligt).
	Verblijfsduur intensieve zorgen
	opnamedatum, opname-uur
	aard van opname (spoedopname, vooraf geplande opname, interne overplaatsing,...)
	regeling voor spoedopname in het geval van ongevallen
	de persoon of instelling die de patiënt verwijst naar het ziekenhuis
	datum en uur van ontslag
	aard van ontslag (bv. op of tegen medisch advies, overleden...)
	bestemming van de patiënt (naar huis, transfer naar een ander specialisme in het ziekenhuis, naar een ander ziekenhuis, naar een rust- en verzorgingstehuis, overleden,...)
	hoofddiagnose en nevendiagnoses + graad van zekerheid (waarschijnlijk, zeker,...)
	chirurgische en gynaecologische interventies
	datum van ingreep (heelkundig en verloskundig)
	graad van dringendheid
	Code anesthesie (geen, lokale.)
	de verblijfsduur in ICU

De registratie van Minimale Verpleegkundige Gegevens (MVGs) werd ontwikkeld op vraag van de Minister van Volksgezondheid en Leefmilieu om, in functie van de optimalisering van het gezondheidsbeleid, informatie te verschaffen over de verpleegkundige activiteit in de ziekenhuizen ([4]) . Belangrijk is op te merken dat de MVGs niet permanent geregistreerd worden, doch tijdens 4 steekproefperioden per jaar: telkens van de eerste tot en met de vijftiende van de maanden maart, juni, september en december. Tijdens de steekproefperiodes moeten de MVGs per verpleegeenheid en per patiënt voor elk van de 15 dagen geregistreerd worden. Nadien worden er 5 dagen geselecteerd door het Ministerie van Volksgezondheid en Leefmilieu. Enkel de gegevens voor deze 5 dagen moeten via magneetdrager voor verwerking overgemaakt worden. Tabel 3.4. vat samen welke gegevens via de MVG registratie kunnen verzameld worden.

TABEL 3.4. DE MINIMALE VERPLEEGKUNDIGE GEGEVENS

algemene gegevens betreffende de instelling, de verpleegeenheid en de patiënt
de uitgevoerde verpleegkundige activiteiten (onderverdeeld in 23 items)
de medische hoofddiagnose (ICD-9-CM code op 3 cijfers)
personeelsgegevens per verpleegeenheid

Voor wat betreft de Minimaal Financiële Gegevens (MFG) is het mij op dit moment niet duidelijk in hoeverre dit soort van gegevens reeds concreet verzameld worden. De MFGs zijn een samenvatting van de facturatiegegevens voor bepaalde prestaties (Closon, 1992). Daar MFGs ook op het niveau van de patiënt worden opgemaakt, kan een idee verkregen worden in het verbruik van de middelen in functie van het type van pathologie.
Tabel 3.5. is een samenvatting van de data-items die via de MFGs zouden kunnen verzameld worden. De verzameling van MFG veronderstelt dat bij elke prestatie of bij elke afgifte van het geneesmiddel plaats en datum vermeld moeten worden, evenals de identificatie van de patiënt (Beeckmans, 1986, p.246).

[4]. Op basis van 'Handleiding voor de registratie van de Minimale Verpleegkundige Gegevens', versie 2, Ministerie van Volksgezondheid en Leefmilieu, 3 Februari, 1992.

TABEL 3.5. DE MINIMAAL FINANCIËLE GEGEVENS

de verblijfsduur van een patiënt
medisch honorarium
patiëntidentificatienummer
farmaceutische produkten (apotheek)
bloed- en bloedderivaten
synthesemateriaal

De betrouwbaarheid van deze secundaire gegevens moet wel gecontroleerd worden. Bij onvoldoende accuraatheid en bij afwezigheid van andere bronnen zal het medisch dossier moeten geraadpleegd worden.

Hoewel de bovenstaande gegevensbronnen reeds een aantal van de gewenste gegevens kunnen verschaffen, blijft vooral het meten en toewijzen van het verbruik van 'resources' een probleem. Voor wat betreft het middelenverbruik zijn er twee belangrijke informatiebronnen die nog niet vermeld zijn: de facturatiegegevens en het verpleegkundig dossier. Beiden kunnen gegevens verschaffen over activiteiten. In de facturatie komt het middelenverbruik aan bod. De facturatiegegevens zijn voorzien van een datum waarop de prestatie plaatsgrijpt. De facturatie gebeurt wel aan de hand van een RIZIV-nomenclatuur. Maar het is mogelijk deze RIZIV-nomenclatuur te converteren naar ICD-9-CM codes. Dit is echter geen 1-1 relatie. Het beslag op verpleegkundige capaciteit kan niet op basis van facturatiegegevens achterhaald worden.

Het verpleegkundig dossier is belangrijk in verband met activiteitengegevens. Het is zelfs nuttiger dan het medisch dossier dat veel meer de klinische aspecten behandelt. Een verpleegkundig dossier bevat een opnameprofiel waarin opnamedatum, wijze van opname (ambulant, rolstoel, brancard), de herkomst van de patiënt (spoedopname, polikliniek, en transfer of andere), voorgaande contacten met gezondheidszorg vermeld worden. Er is ook een programmablad dat datum van aanvraag van consulten en onderzoeken, en datum en uur van planning van consulten en onderzoeken, en van bloedafname vermeldt. Dan is er een informatieblad waarop de ergotherapeutische, de logopedische, de kinesitherapeutische gegevens vermeld staan als ook een samenvatting van de gegevens uit het medisch dossier (anamnese en diagnose) en de behandeling en evolutie (uit het medisch dossier). Vervolgens is er een medicatieblad dat aantoont welke medicatie wanneer moet gegeven worden en gegeven is. Hierop vindt men ook het soort voeding dat de patiënt moet krijgen, of er sondevoeding is of niet, en of de patiënt nuchter moet blijven. Ook de datum van operatie wordt vermeld. Dan is er het eigenlijk verpleegkundig dossier (zorgenplan) dat de activiteiten van de verpleegkundigen continu registreert (zie scores van MVG). Vervolgens is er een tarificatieformulier (in te vullen door de polikliniek) . Het geeft aan voor verschillende procedures (bv. dopler, EKG,...) wanneer (op welke datum) ze plaats gevonden hebben. Het verpleegkundig dossier wordt in het medisch dossier opgenomen. Een verpleegkundig dossier is dienstgebonden. Een dossier gaat wel mee met de patiënt in het gehele ziekenhuis. De betrouwbaarheid en accuraatheid van de gegevensregistratie in het verpleegkundig dossier is sterk verschillend van dienst tot dienst. **Volgens de directie nursing kan een screening van de verpleegkundige dossiers retrospectief geen voldoende basis zijn voor werklastmeting, vooral niet voor wat betreft de directe patiëntenzorg.** De verpleegkundige registratie blijkt sterk onvoldoende te zijn in cardiologie en hartchirurgie. Het is wel belangrijk in te zien dat MVGs maar enkel registreren wat opgeschreven is in het verpleegkundig dossier. Tijdens een MVG registratieperiode is er een betere kwaliteit van de gegevens in het verpleegkundige dossier. Soms worden tijdens de MVG registratieperiode wel eens prestaties genoteerd die niet geleverd werden (om de MVG punten op te voeren).

Andere te exploreren bronnen zijn de gedetailleerde planningssystemen en staffingssystemen, die te vinden zijn op de verschillende diensten in het ziekenhuis..

Een andere manier voor het verzamelen van deze gegevens is te starten met een analyse van de medische dossiers van een bepaalde patiëntengroep. Daarna worden alle medische en paramedische personen die een belangrijke rol spelen bij het verzorgen van dit soort van patiënten samengebracht om de belangrijkste interventies van verschillende diensten op een tijdslijn te plaatsen, en indien mogelijk het middelenconsumptiepatroon te beschrijven. Hierbij wordt uitgegaan van een patiënt met een normaal ziekteverloop. Het is met andere woorden de bedoeling om generische en tijdsgefaseerde consumptieprofielen op te stellen. Deze methode toont een sterke gelijkenis met de methode voor het ontwikkelen van 'kritische paden'. Deze methode vraagt wel een grote input van de medische en paramedische personen werkzaam op de desbetreffende diensten. Het voordeel is echter wel dat een diepgaande activiteitenanalyse wordt uitgevoerd. Deze methode vereist het samenbrengen van alle experts met betrekking tot een bepaald ziektebeeld. De delphi-methode zou hier wel eens op zijn plaats kunnen zijn.

Een laatste mogelijkheid voor het verzamelen van gegevens over patiëntenbewegingen is gebruik te maken van het al dan niet automatisch 'opname-ontslag en transfer' systeem (ADT = Admission, Discharge, Transfer). De aanwezigheid van een dergelijk systeem garandeert niet dat de gewenste gegevens kunnen verzameld worden. Voorafgaande studie van het ADT systeem is een noodzaak (voor zover zo'n systeem in het ziekenhuis bestaat).

Als een algemeen besluit wordt er een relatie gelegd (zie tabel 3.6.) tussen de gewenste gegevens (tabel 3.1) en de te gebruiken datacollectie strategieën (tabel 3.2). Voor sommige gegevens worden meerdere strategieën opgegeven. In sommige gevallen vullen deze strategieën elkaar aan; in andere gevallen zijn het alternatieven.

TABEL 3.6. GEGEVENS EN DATA-COLLECTIE STRATEGIEËN

GEGEVENS	DATA COLLECTIE STRATEGIE
Datum en uur waarop de patiënt wordt opgenomen	MKG, opname-administratie, medisch dossier
De dienst of eenheid waar de patiënt initieel is opgenomen	MKG, opname-administratie
Datum en uur waarop de patiënt uit het ziekenhuis wordt ontslagen	MKG, opname-administratie, medisch dossier
De bestemming van de patiënt na ontslag	MKG
De DRG-classificatie van de patiënt	MKG
Het middelenverbruik van deze patiënten voor de gehele verblijfsduur en dit voor kritische resources	MVG, MFG, facturatiegegevens, operatie-planningssystemen, staffing systemen, verpleegkundig dossier, Delphi-techniek, medisch dossier
Bepalen wat de 'kritische resources' zijn	Observatie van het systeem en interviews met experts
De diensten (locaties) waar de patiënten verblijven, meer bepaald de volgorde der locaties	Medisch dossier of het ADT systeem
Datum en uur waarop de patiënt in elke dienst aankomt	MKG (voor ICU), medisch dossier, ADT systeem
Het middelenverbruik in elke dienst of locatie. Geen beperking tot kritische middelen.	MVG, MFG, facturatiegegevens, operatie-planningssystemen, staffing systemen, verpleegkundig dossier, Delphi-techniek, medisch dossier (op niveau van elke dienst of locatie)
Definiëren van welke 'resources' in elke dienst in beschouwing moeten genomen worden	Observatie van de werking van elke dienst en interviews met experts
De capaciteit en de bezettingsgraad van elke dienst of locatie en de factoren die de bezetting bepalen	Opname-administratie, boekhoudkundige gegevens, detailplanning, observatie en interviews
Variabelen zoals geslacht, leeftijd, socio-economische status, medische historiek, reden voor opname, opname-diagnose, risicograad, en andere factoren die het middelenverbruik en/of de doorstroming van patiënten kunnen beïnvloeden.	Opname-administratie, medisch dossier, MKG
De medische procedures uitgevoerd tijdens het verblijf van de patiënten	MKG, medisch dossier
Nagaan wat de gebruikte patiëntclassificatie is	Observatie en interviews
Geplande en niet geplande patiënten (spoedopnames)	MKG

4. Uitvoering van de datacollectie

Voor wat betreft de data-captatie via de verschillende gegevensbestanden verwijzen we naar hoofdstuk 2.3. in het doctoraat. Bij het analyseren van de gegevensbestanden hebben we ons beperkt tot de secundaire gegevensbronnen. Als niet-geneesheer was het onmogelijk om het medisch dossier en het verpleegkundig dossier in te kijken en te interpreteren. Deze verzameling via secundaire gegevensbronnen werd aangevuld met een aantal interviews. Tabel 4.1. toont de functies van de personen met wie tussen juli 1993 en december 1993 gesprekken werden gevoerd. In februari 1995 werd een presentatie van de resultaten van de gegevensanalyse gehouden voor de Algemeen Directeur en het Hoofd van de dienst Medische Informatica.

Tabel 4.1.. Een overzicht van de functies van de personen met wie gesprekken werden gevoerd

Algemeen directeur
Financieel directeur
Hoofdgeneesheer
Diensthoofd hartchirurgie
Diensthoofd anesthesie
Directie verpleging (3 personen)
Commissie voor Medische ethiek
Dokter (in opleiding) hartchirurgie
Hoofdverpleger hartchirurgie
Dokter Hart- en Vaatziekten
Hoofdverpleegkundige Hart- en Vaatziekten
Dokter Catheterisaties
Verpleegkundige Catheterisaties
Dokter tewerkgesteld in een labo
Verpleegkundige tewerkgesteld op de radiologie
Hoofdapotheker
De dienst medische informatica
De dienst facturatie

5. Een beschrijving van de te modelleren diensten

Hier beschrijven we het dienstverleningsproces van de diensten Hart - en Vaatziekten en Hartchirurgie. Hoofdstuk 2.2. en hoofdstuk 3.3. in het doctoraat maken gebruik van deze beschrijving.

5.1. Hart- en Vaatziekten

5.1.1. DE CASE-MIX

Alle patiënten (poliklinisch en hospitalisatie) moeten zich aanmelden aan dezelfde receptie. De receptie heeft ook een terminal die verbonden is met het centraal informatiesysteem. Hier worden de prestaties ingegeven (niet noodzakelijk op de dag dat de prestatie geleverd wordt).

De hart- en vaatziekten kunnen onderverdeeld worden in drie grote categorieën:

1. ritme-afdeling: problemen met hartritmes, pacemakers,...
2. coronaire aandoeningen: catheterisaties, dilataties, infarcten,...
3. vaataandoeningen en hypertensie

De ritme-afdeling bevindt zich op de 10e verdieping van K12. Hier komen de patiënten terecht met problemen op het vlak van hartritmes, voor pacemakers (controle) en ingeplande defibrilatoren (controle). Er is ook een diagnostisch luik, namelijk electro-fysiologisch onderzoek. Dit gebeurt in een lokaal op de twaalfde verdieping in IZ zelf.

Coronaire patiënten zijn patiënten die pijn hebben aan het hart, een benauwd gevoel hebben (angor, beklemming), patiënten die een infarct doorgemaakt hebben. Het zijn dus patiënten bij wie er problemen zijn met de bevloeiing van het hart.

Deze drie categorieën patiënten zijn niet mutueel exclusief. Patiënten kunnen aandoeningen hebben die tot meer dan 1 categorie behoren (ook buiten hart- en vaatziekten).

De volgende begrippen vereisen enige verduidelijking:
Een catheterisatie (of coronarografie) is een onderzoek naar de toestand van de doorgankelijkheid van de coronairen of de kransslagaders (bloedvaten rond het hart, die de zuurstof aan de hartspier geven). Een catheterisatie omvat het inbrengen van een catheter (hol buisje) via een slagader in de lies of de arm tot het hart. Via deze sonde kunnen verschillende onderzoeken uitgevoerd worden.
Een infarct wordt veroorzaakt door een verstopping van zo'n bloedvat. Naargelang de grootte van het bloedvat heeft dit een gevolg voor de ernst van de aandoening.

Wanneer catheterisatie een diagnostische procedure is, dan is dilatatie een therapeutische procedure die plaatsvindt tijdens catheterisatie. Via de catheter wordt een balloncatheter aangebracht tot op de plaats van de vernauwing van kroonslagaders. Ter hoogte van de vernauwing wordt het ballonnetje opgeblazen om aldus de kroonslagader te verwijden. Niet elke vernauwing kan met de ballondilatatie verholpen worden. Soms is een heelkundig ingrijpen (operatie met overbrugging of CABG) noodzakelijk.

Na diagnose zijn er in principe 2 richtingen mogelijk qua behandeling: de behandeling via geneesmiddelen, en een heelkundig ingrijpen indien geneesmiddelen onvoldoende zijn.

Fundamenteel bestaat de dienst uit een polikliniek en een hospitalisatie-afdeling. Deze twee afdelingen zijn organisatorisch goed onderscheidbaar in de zin dat de polikliniek onder de bevoegdheid van de hoofdgeneesheer (medisch-technische dienst) valt, en de hospitalisatie onder de bevoegdheid van de nursing.
Slechts 1 à 2 op 100 patiënten die zich aanmelden in de polikliniek worden rechtstreeks opgenomen in de hospitalisatie.

De meeste gehospitaliseerde patiënten komen terecht op de verpleegeenheden die nu gelokaliseerd zijn op IBO6, IB08 en IB10. IB08 is de eigenlijk verpleegeenheid van hart- en vaatziekten. We richten onze aandacht in de eerste instantie dan ook op deze afdeling. Via de diagnoseprofielen op basis van de MVG registratie in 1992 kan een inzicht verworven worden in de case-mix van de cardiologie, en wel in termen van ICD-9-CM codes (zie tabel 5.1.). De 16 diagnosen vermeld voor IB08 omvatten ongeveer 75% van het aantal patiënten in de steekproef. De overige 25% zijn verdeeld over een lange lijst van andere codes waarbij geen enkele categorie een relatief aandeel dat groter is dan 0.90% heeft.

TABEL 5.1. HET DIAGNOSEPROFIEL VAN DE VERPLEEGAFDELINGEN IB08

CODE	BESCHRIJVING	RELATIEVE DIAGNOSE VERDELING (%)
411	Overige acute en subacute vormen van ischemische hartaandoeningen	12.61
427	Hartdysritmieën	11.71
410	Acuut Myocard Infarct	10.81
413	Angina Pectoris	8.56
414	Overige vormen van chronische ischemische hartaandoeningen	6.31
428	Hartdecompensatie	6.31
429	Niet scherp omschreven ziektebeelden en complicaties	3.60
440	Artherosclerose	3.15
424	Overige aandoeningen van het endocard	2.70
780	Algemene symptomen	2.70
786	Symptomen van de ademhalingswegen en overige symptomen	2.70
394	Aandoeningen van de mitraalklep	1.35
395	Aandoeningen van de aortaklep	1.35
426	Geleidingsstoornissen	1.35
443	Overige perifere vaatziekten	1.35
453	Overige veneuze embolie en trombose	1.35

* gegevens voor 227 patiënten die gedurende minstens één van de 20 door het ministerie geselecteerde dagen op IB08 aanwezig waren in 1992.

Tijdens de laatste MVG registratieperiode in 1992 had 9.5% van de 49 patiënten op IB10 (die in de steekproef betrokken waren) een diagnose '411 OVERIGE ACUTE EN SUBACUTE VORMEN VAN ISCHEMISCHE HARTAANDOENINGEN' en 4.8% had een diagnose '413 ANGINA PECTORIS'.

5.1.2. DE POLIKLINIEK

De polikliniek stelt 7 verpleegkundigen tewerk: 4 gegradueerden in de verpleegkunde (A1), 2 verpleegassistenten, 1 kinderverzorgster. Er zijn 5 medisch secretaressen en 3 administratieve personen. Er zijn 4 technici tewerkgesteld. Er is 1 geschoolde werknemer als hulp.

De belangrijkste uitrusting van de polikliniek is: 4 EKG toestellen, 2 toestellen voor vectorcardiogrammen, 2 echo-dopler toestellen, 1 OPG-dopplerscanner, een vaatlabo, 2

catheterisatiezalen. Een vectorcardiogram is in staat nog meer gegevens over hart en spierweefsel te onttrekken dan een ECG. Een echo-dopler toestel bestudeert het hart op een niet-invasieve wijze. Met een echodopler toestel kan een echocardiogram gemaakt worden. Dit laat toe om de structuren van het hart te visualiseren. Dit gebeurt door ultra sonore golven uit te zenden en de teruggekaatste golven te registreren op foto en op papier. Een echocardiogram wordt zowel pre-operatief als post-operatief uitgevoerd voor alle coronarografie patiënten. Eén echodopler toestel kan 26 - 28 patiënten per dag verwerken (tussen 8 en 17.00 uur). Het tweede toestel wordt meer als een reserve beschouwd of ten behoeve van stagairs en noodsituaties.
Een OPG-doppler toestel wordt gebruikt in verband met problemen met vaten (geen hart). In het vaatlabo worden bijkomende diagnostische onderzoekingen gedaan naar aandoeningen op het gebied van niet-coronaire bloedvaten (bv. armen, benen, vingers). Catheterisatie werd hiervoor reeds uitgelegd. De procedure wordt verricht in speciaal hiervoor uitgeruste catheterisatiezalen.

5.1.3. HOSPITALISATIE

Patiënten die moeten opgenomen worden (hospitalisatie) kunnen op verschillende plaatsen terechtkomen: de hospitalisatie-afdeling van hart- en vaatziekten op 8K12, de 'coronary care unit' (IZ) op 12K12 of op één van de 'pool' afdelingen, toegewezen door de centrale opname-administratie. Deze 'pool' verdiepingen zijn vooral 6IB (K12) of het 5e. Patiënten komen soms terecht op de geriatrie, op dermatologie, pneumologie,...... Patiënten die geplaatst worden op 'pool' verdiepingen blijven op deze verdiepingen in het geval het verblijf kort is (zoals bv. patiënten die een coronarografie hebben ondergaan). Transfer zou een te grote administratieve rompslomp met zich meebrengen. Het is ook niet voordelig voor de patiënt.
Binnen cardiologie bestaat er geen toewijzing van bepaalde bedden aan patiënten met een bepaalde pathologie. Er zijn echter wel reserveringen voor de geplande opnames van coronarografie patiënten. Er wordt een bepaald percentage bedden vrijgehouden voor spoedopnames en dringende opnames via een andere ziekenhuis. De meerderheid zijn echter geplande opnames.
De CCU (Coronary Care Unit) moet beschouwd worden als de Intensieve Zorgen voor coronaire patiënten. Men is ook bezig om een midcare in te richten die zal instaan voor de verzorging van patiënten tussen IZ en de gewone hospitalisatie.

Er zijn ongeveer 2700 hospitalisaties op jaarbasis (op basis van het aantal brieven). Deze hospitalisaties bestaan vooral uit ischemische hartaandoeningen, overige hartaandoeningen (samen 60%) en vaataandoeningen en hypertensie (20%). Bij de ischemische hartaandoeningen zijn hartdecompensatie en infarcten veel voorkomend. Bij de overige hartaandoeningen zijn vooral ritmestoornissen van belang. De hartdecompensaties zijn de chronisch zieken, die altijd terugkomen. De ritmestoornissen betreffen dikwijls jonge mensen. Hartinfarcten omvatten ook veel jonge mensen (30, 40, 50 jaar). Bij hartinfarcten worden dikwijls coronarografieën uitgevoerd. Bij vaataandoeningen zijn ziekten van arteriën en arteriolen, en van venen en lymfewegen veel voorkomend. Acuut gewrichtsreuma, chronische reumatische hartaandoeningen, acuut pulmonaire aandoeningen komen weinig voor. Congenitale afwijkingen komen ook voor.

Voor de coronaire patiënten is de volgende uitrusting van belang: toestellen voor electrocardiogram, vectorcardiogram en echo-doppler.

De belangrijkste andere klinisch ondersteunende diensten zijn: radiografie (long-hart) en labo (bloed en urine onderzoeken). Verder spelen de sociale verpleegkundige en de psycholoog van hartrevalidatie ook wel een belangrijke rol.
De radiografie is 1 afdeling. Er zijn verschillende labo's.

Er zijn verschillende locaties waarop patiënten terechtkomen: 8K12, 6K12, en 10K12.
Op 8K12 worden alle gevallen van cardiologie opgenomen. Op 6K12 worden uitsluitend coronairen opgenomen. Daar komen al de geplande patiënten die een coronarografie moeten hebben. Een belangrijk verschil tussen de opnames op 8K12 en 6K12 is dat de meeste patiënten op 8K12 (via spoedopname) van Intensieve Zorgen komen en dus geen geplande opnames zijn. Op 10K12 (CCU) komen de patiënten met ritmestoornissen terecht.
Met andere woorden, er is een relatie tussen de specifieke diagnose van de patiënt en de locatie waar hij/zij gehospitaliseerd wordt. Het is deze indeling die gebruikt wordt voor verdere analyse van patiëntenstromen.

5.1.4. PROCESBESCHRIJVING VOOR PATIËNTEN OPGENOMEN VOOR CATHETERISATIE OF CORONAROGRAFIE

Dergelijke coronaire patiënten worden meestal gepland voor coronarografie (catheterisatie). Coronarografie kan zowel een diagnostisch als een therapeutisch doel hebben. In het eerste geval is meestal het probleem wel gekend, maar niet de diagnose. In sommige gevallen wordt na operatie een coronarografie genomen om te checken. In dit geval is de diagnose natuurlijk wel al gekend. Het therapeutisch doel van catheterisatie is dilatatie. Dilatatie kan gebeuren samen met een coronarografie of afzonderlijk.

Coronarografie vereist altijd opname van de patiënt. Deze patiënten komen meestal op 6K12 terecht (soms op 8K12 en soms nog op andere afdelingen naargelang er plaats is). 6K12 is een 'pool' hospitalisatie-afdeling waar prioritair patiënten voor catheterisatie en een gedeelte van de reumato-patiënten liggen. Er blijft weinig plaats over om nog andere specialiteiten op te nemen (het gebeurt soms dat patiënten van andere specialiteiten (zoals endocrinologie, algemeen interne,....) op 6K12 komen. Ongeveer 2/3 van de patiënten zijn patiënten die wachten op catheterisatie of coronarografie.

De meeste (90%) van deze patiënten zijn van buiten het ziekenhuis verwezen. Ongeveer 2/3 komen rechtstreeks van thuis; en ongeveer 1/3 komt van een ander ziekenhuis. Dit zijn meestal patiënten met angor, hartinfarcten en klepaandoeningen. Die 90% patiënten zijn gepland. 10% komen van de eigen hospitalisatie (ongeveer evenredig verdeeld over spoedopname, intensieve zorgen en polikliniek). De spoedopnames gebeuren meer frequent overdag dan 's nachts. De opnames via spoedopname zijn dan echter zo acuut dat ze van spoedopname naar IZ gaan. In die 10% bevinden zich patiënten met coronair lijden, met ritmestoornissen, met hypertensie,.... Sommige patiënten komen meer dan 1 maal gedurende hetzelfde verblijf naar de catheterisatie-afdeling. Dit gebeurt echter niet frequent en enkel bij ingrepen met therapeutische doelstellingen (dilataties). De patiënten komen dan terug naar de catheterisatie afdeling voor een controle.
60% van de patiënten gaat na ontslag naar huis en 30% gaat naar een ander ziekenhuis. 5% gaat naar hartchirurgie. Er zijn geen overlijdens.

Coronarografie gebeurt bij patiënten met verschillende pathologieën. 80% van de patiënten op de catheterisatie-afdeling hebben een coronaire pathologie (hartinfarct of angor) en 20% hebben een kleppathologie. Acute hartinfarcten komen niet zoveel voor op 6K12 (enkel in het geval dat het acuut hartinfarct aanleiding geeft tot catheterisatie). Het basisleiden voor catheterisatie is angor. Op jaarbasis behoren 1600 van de 2000 patiënten tot de Ischemische Hartaandoeningen (infarct en angor), en 250 van de 2000 hebben klepaandoeningen. 120 patiënten hebben endocarditis. Ritmestoornissen kunnen voorkomen in die zin dat in de groep van 'hart'patiënten er veel patiënten zijn met een ritmestoornis.

Tabel 5.2. vat de diagnostische en therapeutische toepassingen samen.

TABEL 5.2. DIAGNOSTISCHE EN THERAPEUTISCHE TOEPASSINGEN VAN CATHETERISATIE

TOEPASSING	
DIAGNOSTISCH	1. Registratie van de drukken 2. Bepalen van bloedgassen 3. Informatie over de hartfunctie 4. Visualiseren van de verschillende structuren van het hart
THERAPEUTISCH	1. Percutane transluminale angioplastie 2. Klepdilataties 3. Septostomie 4. Toediening van medicatie 5. Evacuatieve pericardpunctie

De belangrijkste procedures worden in tabel 5.3. weergegeven. Coronarografie bestaat uit het visualiseren van het hart. Rechts/links catheterisatie zijn drukmetingen. PCTA zijn coronaire dilataties. Dit staat tegenover aortaklep-dilataties. Ook wordt het aantal procedures voor 1992 aangegeven. Het totaal aantal procedures voor 1992 bedroeg 2308. Dit is een stijging met 22% ten opzichte van 1991 (1892 procedures). Tabel 5.4. geeft het aantal procedures voor de opeenvolgende jaren weer. Hier moet wel opgemerkt worden dat één patiënt wel meerdere procedures kan ondergaan. Rechts/links catheterisatie gaat meestal gepaard gaan met een coronarografie. De PTCA kan ook gepaard gaan met coronarografie en/of catheterisatie. Op basis van het aantal brieven waren er 1642 patiënten in 1992. Aortaklep-dilataties komen heel zelden voor.

TABEL 5.3.. DE BELANGRIJKSTE PROCEDURES IN DE CATHETERISATIE-ZAAL

SOORT PROCEDURE	AANTAL (1992)
Coronarografie	1495
Rechts/links catheterisatie	220
PCTA (percutane transluminale angioplastie of ballondilatatie)	426
Andere (andere hemodynamische onderzoeken)	40
Pediatrie	127
Aortaklepdilatatie	0

TABEL 5.4. TOTAAL AANTAL PROCEDURES VOOR OPEENVOLGENDE JAREN

JAAR	# PROCEDURES
1988	960
1989	1011
1990	1298
1991	1892
1992	2308

Patiënten met een kleppathologie hebben meestal een catheterisatie nodig. Patiënten met een coronaire pathologie vragen een coronarografie aan.

De nood aan een catheterisatie of een coronarografie blijkt uit een voorafgaand poliklinisch onderzoek dat o.m. een EKG, een inspanningsproef en een klinisch onderzoek omvat. Voor iedere pathologie bestaat een bepaald protocol.

De urgentie van het onderzoek bepaalt wanneer de patiënt voor opname gepland wordt. Een coronarografie wordt nagenoeg altijd minstens twee dagen op voorhand gepland. Soms is directe opname noodzakelijk. Planning betreft hier zowel de planning van de hospitalisatie als van de catheterisatie. Het is een vrij sterk gestandaardiseerde procedure over 3 dagen (dit is dan ook de officiële gemiddelde verblijfsduur): één dag voor de ingreep, de dag van de ingreep en een dag na de ingreep. De belangrijkste interventies zijn:

Pre-operatief (dag 1): Bloedonderzoek
Foto long en hart (Rx thorax)
Echocardiogram
Ingreep (dag 2) Vervoer naar Cathlab
Catheterisatiezaal
Recovery Room
Vervoer naar kamer
Post-operatief (dag 3)EKG
Bloedafname

Verder moet de patiënt nuchter blijven als het onderzoek in de namiddag plaatsvindt. Als het niet in de namiddag plaatsvindt, wordt het uitgevoerd in de voormiddag van de volgende dag. Gedurende de eerste dag komt de arts bij de patiënt, neemt de anamnese door en geeft bijkomende uitleg. Ook de verpleging geeft bijkomende uitleg.

Dilatatie-patiënten blijven gemiddeld 1 dag langer in het ziekenhuis omdat ze na de dilatatie naar IZ gaan en omdat de arteriële catheters 24 uur langer blijven zitten en ze ten vroegste 24 uur na het verwijderen van de arteriële catheter naar huis mogen.
De verblijfsduur wordt vooral beïnvloed door de leeftijd en bijkomende pathologieën (complicaties, bv. ritmestoornissen). De meeste patiënten zijn tussen 45 en 55 jaar oud. Sommige patiënten die van een ander ziekenhuis komen, worden de dag zelf nog naar dit ander ziekenhuis teruggevoerd. Dit is het geval voor één bepaald ziekenhuis. Dergelijke patiënten die maar 1 dag blijven, zijn een typisch voorbeeld van een 'bedinname'.

De eigenlijke catheterisatie gebeurt in één van de twee catheterisatiezalen op de vijfde verdieping (K12) en neemt gemiddeld 1 uur in beslag (45 tot 60 minuten voor coronarografie; 1 tot 1,5 uur voor Links/Rechts catheterisatie; 1,5 tot 2,5 uren bij kinderen). Daarna wordt de patiënt nog 1/2 of 1 aanvullend uur voor controle op de recovery room gehouden. De 3 recovery rooms bevinden zich aanpalend bij de catheterisatiezalen. Hier wordt het bloed, de pols en het verband gecontroleerd (voor eventuele bloedingen). De capaciteit van de recovery rooms blijkt niet voldoende te zijn. Dan wordt de patiënt teruggebracht naar de kamer op de hospitalisatie-afdeling van cardiologie (IB06,K12). Daar blijft hij overnachten. Als er geen problemen zijn, wordt hij s'anderendaags ontslagen. Hij krijgt een ontslagbrief mee die gericht is naar de huisarts. Patiënten gaan dan meestal naar huis. In het geval de patiënt van een ander ziekenhuis komt, gaat hij/zij de dag van de ingreep zelf nog naar dat ander ziekenhuis terug (ambulant). Er zijn ook overlijdens op de dienst (slechts 2 per duizend).

Er zijn echter ook coronaire patiënten die een chirurgische ingreep nodig hebben (10 à 20 %). Die gaan dan ofwel onmiddellijk naar Intensieve Zorgen ofwel op dag (-2) naar hartchirurgie; ofwel gaan die patiënten eerst naar huis en wordt er een chirurgische ingreep gepland. Als de hartchirurgie geen bedden heeft, kan het gebeuren dat de patiënt maar op dag (-1) of zelfs op de dag van operatie zelf naar hartchirurgie gaat. De pre-operatieve onderzoeken gebeuren dan op IB06.
Patiënten die een dilatatie ondergaan (in de afdeling hartcatheterisatie) gaan voor een nacht naar Intensieve Zorgen. Het is belangrijk op te merken dat Intensieve Zorgen een beperking is op het aantal hospitalisaties voor catheterisatie. De IZ kan immers niet volgen.

Er kunnen 10 patiënten per dag per catheterisatiezaal behandeld worden (tussen 8 en 17.00 uur). Het absolute maximum is 15 per dag in optimale omstandigheden. De catheterisatiezalen liggen zeer dicht bij de chirurgie (5e verdiep). In een beperkt aantal gevallen (2 à 3 % per jaar) is een onmiddellijke operatieve ingreep noodzakelijk. Dit is meestal bij dilatatie. Daarom is het belangrijk dat bij het uitvoeren van een dilatatie een operatiezaal beschikbaar is. De meeste dilataties worden dan ook over de middag uitgevoerd omdat dan op zijn minst 1 operatiezaal vrij is.

De catheterisatie is vrij duur. Een catheter kost algauw 9000 Bef. Er bestaat de neiging tot overconsumptie van hartcatheterisatie.

Het personeel vormt de meest beperkende factor in de produktie van de afdeling. Men werkt met 4 FTEs (Verpleegkundigen A1), 2 secretaressen en twee technici. De dienst is open van 8 tot 17 uur maar heeft een permanente wachtdienst.

De hospitalisatie-afdeling (6K12) heeft 29 bedden en 15.75 FTE personeel (18 personeelsleden waarvan 7 A1s, 8 A2s en 3 verpleegassistenten) en 2 geneesheren. Deze afdeling heeft als uitrusting een EKG-toestel. Er zijn een aantal specifieke bedden voor reumato-patiënten (± 10 orthopedische bedden). De bezettingsgraad van 6K12 is rond de 75 %. De bezetting tijdens het weekend is laag. Dit beïnvloedt het totaal. Ook de planning beïnvloedt de bezettingsgraad. Wanneer bijvoorbeeld in de namiddag de opname van 8 personen gepland is, kan in de voormiddag niemand meer opgenomen worden hoewel de afdeling niet vol is. De werklast is niet te zwaar. Tijdelijke overbelasting komt zelden voor (doordat er iemand acuut wegvalt, of de werklast verkeerd ingeschat is of plots veranderd is). Bij tijdelijke overbelasting wordt eerst intern een oplossing gezocht: bijvoorbeeld de hoofdverpleegkundige wordt ingeschakeld. Bijstaffing gebeurt zelden of nooit. Patiënten van hart - en vaatziekten die op IB06 liggen, worden niet getransfereerd wanneer plaats vrij komt op IB08.

Een voorbeeld van de complexiteit van het planningsproces:
De hoofdverpleegkundige weet op voorhand wie gepland is voor een catheterisatie (weekplanning). Hier komen wel variaties voor: een catheterisatie die plots gepaard gaat met dilatatie, een geplande dilatatie die plots niet doorgaat. Patiënten kunnen langer blijven liggen omdat ze moeten geopereerd worden. Er is ook nog de balans met de andere opnames van reumatologie. Het geslacht speelt ook een rol ("twee vrouwen gepland op kamer 25, maar een mannelijke patiënt blijft onverwachts op die kamer liggen omdat hij moet geopereerd worden"). Anderzijds zijn er patiënten die onmiddellijk naar IZ gaan waardoor er een bed vrijkomt.

De belangrijkste klinisch ondersteunende diensten voor de catheterisatie-afdeling zijn radiologie en laboratorium. De communicatie met deze diensten is niet goed. Men krijgt de resultaten niet op tijd. Recentelijk werd een oplossing gevonden door een printer voor laboresultaten te installeren op de catheterisatie-afdeling. Het wachten op de resultaten zou impliceren dat maar de helft van de huidige capaciteit kan gebruikt worden.

De belangrijkste klinische ondersteunende diensten voor de hospitalisatie op IB06 zijn de polikliniek van de cardiologie en de radiologie. Naargelang van het soort onderzoek, wordt er contact opgenomen met een bepaald persoon op de polikliniek (bv. een persoon verantwoordelijk voor de echocardiografie, voor de echodopplers,...). Alles is op afspraak. Er bestaat geen prioriteit voor gehospitaliseerde patiënten boven poliklinische patiënten. Soms zijn er wel periodes voorbehouden voor enkel poliklinische patiënten (bv. echocardiogram), tenzij het dringend is. Er is een relatief goede relatie. De patiënten moeten niet lang wachten voor de technische prestaties.
Elke patiënt die komt voor een coronarografie moet een Rx thorax (radiologie) hebben. De resultaten van het radiologisch onderzoek worden rechtstreeks gestuurd naar de hartcatheterisatiezaal. De taak van de hospitalisatie op IB06 is enkel ervoor zorgen dat de patiënt op tijd naar de respectievelijke onderzoeken vertrekt.

Belangrijke niet-klinische ondersteunende diensten zijn voeding, materiaal, apotheek.

5.1.5. PROCESBESCHRIJVING VOOR PATIËNTEN DIE GEHOSPITALISEERD WORDEN OMWILLE VAN ISCHEMISCHE HARTAANDOENINGEN (VOORAL HARTINFARCTEN EN ANGINA PECTORIS)

IB08 (8K12)([5]) werd voordien reeds beschreven als de verpleegafdeling van de dienst hart - en vaatziekten. Ischemische hartaandoeningen vormen het leeuwenaandeel van ziektebeelden op deze afdeling. Vaak komen patiënten met ischemische hartaandoeningen binnen via spoedopname, gaan dan naar Intensieve Zorgen (12K12, IA), en komen zo terecht op de hospitalisatie-afdeling (8K12)([6])([7]). Soms zijn de patiënten doorgestuurd vanuit de polikliniek (bv. hypertensie).([8]) Patiënten met dergelijke ziektebeelden kunnen ook op andere afdelingen zoals IB10 terechtkomen.

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[5]. Het is belangrijk op te merken dat de verpleegeenheid die nu op IB08 gelocaliseerd is, voor 21/09/92 op IA08 gelocaliseerd was.

[6]. Dit geldt voor het merendeel van de ischemische hartaandoeningen.

[7]. Reeds vanuit IZ kan een coronarografie gebeuren.

[8]. Voor wat betreft IZ wordt een opsplitsing beoogd tussen IZ voor algemene interne pathologie, en IZ voor coronaire patiënten (coronary care unit of CCU). Dit laatste is echter wel nieuw.

De eerste unit (buiten spoedopname) is ofwel de IZ ofwel de hospitalisatie-afdeling. Patiënten die binnenkomen via spoedopname gaan wel eerst naar de oude IZ vooraan het ziekenhuis. Als ze dan wat beter zijn, komen ze dan naar IZ 12K12. Op IZ liggen patiënten 1,2 tot 3 dagen. Dan gaan ze naar de hospitalisatie-afdeling. Er zijn wel een aantal patiënten (vooral hartdecompensaties, angor) die rechtstreeks van de spoedafdeling naar de hospitalisatie-afdeling gaan.

Patiënten die worden gehospitaliseerd maken gebruik van de uitrusting op de polikliniek naargelang van een programma dat wordt uitgewerkt. Dit programma is voor iedereen ongeveer hetzelfde: een EKG, een vector, een dopler, een fietsproef (revalidatie), eventueel een coronarografie,.... Via de vervoerdienst worden de patiënten van de hospitalisatie-afdeling naar de polikliniek gebracht.

Deze patiënten blijven normaliter langer in het ziekenhuis dan de coronarografie patiënten. Dit is echter wel afhankelijk van de ernst van de aandoening. Er wordt geen risicograad berekend bij opname. Het zijn meestal mannelijke patiënten. Patiënten die op de hospitalisatie opgenomen worden, hebben meestal een diagnose. De einddiagnose komt meestal goed overeen met de opnamediagnose. De patiënten op 8K12 zijn normaliter niet zo zwaar ziek. Van zodra ze pijn voelen in de borst, moet er vlug een EKG gemaakt worden en medicatie gegeven worden.

Patiënten met een infarct met complicaties blijven ongeveer 3 weken. Zonder complicaties blijven ze 2 weken. De gemiddelde verblijfsduur bedraagt (waarschijnlijk) een 11-tal dagen. De leeftijd speelt een rol ten aanzien van de verblijfsduur. Jongere mensen gaan vlugger weg. De diagnose en medische historiek spelen ook een rol. De hartinfarcten en de hartdecompensaties blijven het langst. De ritmestoornissen hebben een korter verblijf (ongeveer een week). Er zit wel een grote standaardafwijking in de verblijfsduur. Ze volgen wel allemaal een beetje hetzelfde programma.

Patiënten die op 8K12 terechtkomen, ondergaan meestal geen chirurgische ingreep. Wanneer bijvoorbeeld bij coronarografie een belangrijk hartletsel wordt ontdekt, blijven die mensen op IZ van de hartchirurgie na de coronarografie. Met andere woorden die komen niet meer terug naar 8K12. Dus hartchirurgie is een afzonderlijke dienst met eigen hospitalisaties. Vanaf het moment dat er een chirurgische ingreep nodig is, verhuizen de patiënten van de dienst Hart - en Vaatziekten naar de dienst Hartchirurgie.

Het gebeurt dat patiënten hervallen. Bijvoorbeeld patiënten die een CABG gehad hebben, en daarna opnieuw angor hebben. Die komen dan wel terug naar de hospitalisatie van hart- en vaatziekten.

8K12 stelt 14,25 FTE tewerk (1 hoofdverpleegkundige, 3,5 gegradueerden (A1), 2,75 gebrevetteerden (A2), 5 verpleegassistenten, 1 secretaresse en 1 ziekenhuishelpster). Er zijn 5 geneesheren waarvan twee assistenten in opleiding.
De werklast van de verpleegkundigen is zeer hoog (aldus de hoofdverpleegkundige). Ze vindt dat er een tekort is aan personeel op 8K12.

Tabel 5.5. toont een aantal gegevens over de werklast van verpleegkundigen op IB08 op basis van de MVG registratie-gegevens. Het is belangrijk deze gegevens te gaan vergelijken met bijvoorbeeld de werklast van andere verpleegeenheden (zoals bijvoorbeeld die van de hartchirurgie).

TABEL 5.5. GEGEVENS I.V.M. DE VERPLEEGKUNDIGE WERKLAST OP IB08

	04/92 (1)	06/92	09/92	12/92
totaal uren (2)	1097	1018	1005	966
# patiënten (3)	81	57	81	68
# pat/dag (4)	28	24	28	27
# uren/dag/pat(5)	2.6	2.8	2.4	2.4
totaalwaarde (6)	11548.75	11623.50	14731.25	10822
patiëntenindex(7)	142.57	203.92	181.87	159.14
werklastindex (8)	10.53	11.42	14.66	11.20

(1) voor elk van deze maanden worden de eerste 15 dagen in beschouwing genomen
(2) dit is het totaal aantal verpleeguren exclusief de uren leerlingen over de 15 dagen
(3) dit is het totaal aantal patiënten over de 15 dagen
(4) dit is het aantal patiënten per dag of het totaal aantal patiënten die in de steekproef van 15 dagen opgenomen is gedeeld door 15
(5) dit is het totaal aantal uren/15 dagen/aantal patiënten per dag
(6) dit is de totaalwaarde van de MVG registratie gewogen aan de hand van PRN-punten
(7) dit is de totaalwaarde gedeeld door het aantal patiënten
(8) dit is de totaalwaarde gedeeld door het totaal aantal uren verpleegkundig personeel.

In het geval van schaarste kan de hospitalisatie-afdeling een beroep doen op de directie nursing voor additioneel personeel. Dit personeel komt dan van andere afdelingen. Onderbelasting wordt gemeld aan de directie nursing. Personeel dat geen werk heeft, wordt in andere afdelingen ingezet. Personeel wordt nooit naar huis gestuurd.

8K12 heeft 29 bedden. De bezettingsgraad van de bedden is ongeveer 80% ([9]). De centrale opnamedienst wijst de bedden toe. Wanneer er geen plaats is op 8K12, worden patiënten toegewezen aan poolverdiepingen. Op de dag van het interview lagen 16 patiënten op pool verdiepingen. Dit kan gaan tot ongeveer 20 bedden. De centrale opnamedienst beslist waar patiënten terecht kunnen. Er is wel een volgorde in de verdiepingen waar de patiënten het best liggen (bijvoorbeeld niet bij de neurologische patiënten). Er is een 'pool' dokter die zorgt voor de patiënten op de pool verdiepingen. Een bepaalde geneesheer wil echter niet dat zijn patiënten (ritmestoornissen) op andere verdiepingen terechtkomen. Infarcten, ritmestoornissen, hypertensie worden dan ook het minst vlug misplaatst. De mate van 'misplaatsting' hangt dus af van de individuele preferentie van de behandelende geneesheer of van de aard van pathologie. Patiënten op een poolverdiep komen terug naar 8K12 als het binnen de 7 dagen is en als de pool dokter het nodig acht. Dus er is geen transfer in het geval van een kort verblijf.
De dienst (8K12) heeft verder 1 EKG toestel.

De belangrijkste ondersteunende diensten zijn radiologie, labo en de polikliniek van hart- en vaatziekten, de revalidatie (10K12, IE), de kinesisten, de sociale verpleegkundigen.
Voor labotesten vragen de dokters bloed aan. Dit wordt gemeld aan de verpleegkundigen want de patiënt moet nuchter zijn. De verpleegkundigen nemen meestal zelf geen bloed meer af. Dit kan gebeuren door een 'prikploeg' van het labo zelf (tussen 7 en 13.00 uur). Hierbuiten wordt ook nog bloed afgenomen. Aan de receptie is er een transportdienst waar gedurende de hele dag om het uur alle bloedstalen afgehaald worden. De resultaten komen dan ook via deze vervoerdienst. De dokters kunnen ook alles opvragen via de computer.
Voor een gewone thoraxfoto (radiologie) mogen de patiënten altijd dadelijk gaan (zonder afspraak). Voor alle overige onderzoeken moeten er afspraken gemaakt worden. Dit houdt in: aanvragen van het onderzoek, schrijven van brieven, de dokters noteren de reden van onderzoek, de vervoerdienst wordt verwittigd, de patiënt wordt afgehaald. Alles gebeurt via de afsprakenplanning van radiologie. Patiënten moeten soms lang wachten (bijvoorbeeld voor CT of scanner). Als het te lang duurt, worden de patiënten naar huis gestuurd en keren ze later poliklinisch of ambulant terug. Sommige patiënten moeten echter een bepaald onderzoek ondergaan voordat ze ontslagen worden. Het kan dus gebeuren dat patiënten langer op de afdeling verblijven ten gevolge van het wachten voor bepaalde onderzoeken.

[9]. De MVG registratie geeft zelf een bezettingsgraad van de bedden tussen 80% en 90% aan. Dit is natuurlijk enkel geldig voor de dagen waarop MVG registratie plaats grijpt.

Ook met poliklinieken worden er afspraken gemaakt. Er is daar natuurlijk de interferentie met de poliklinische patiënten. Er bestaat geen prioriteit voor de gehospitaliseerde patiënten.

De patiënten met een hartinfarct komen op een hartrevalidatie-schema (fietsen, turnen,...).

Een belangrijke niet-klinische ondersteunende dienst is de keuken.

5.1.6. PROCESBESCHRIJVING VAN PATIËNTEN MET RITMESTOORNISSEN

Ritmestoornissen komen ongeveer 50% van huis (via de polikliniek) en 50% van IZ. Na hospitalisatie gaan ze ook meestal naar huis. Die worden verder gevolgd op de ritme-polikliniek.

Patiënten met ritmestoornissen komen op verschillende verpleegeenheden terecht, zoals IB08 (zie tabel 6.1.) en IB10.

Een pacemaker inplanten is een cardiologische ingreep (en dus geen chirurgische ingreep). Die liggen dus op de dienst cardiologie.

We hebben dit soort patiënten niet verder bestudeerd aangezien de betrokken geneesheer niet beschikbaar was.[10]

5.2. Hartchirurgie

5.2.1. DE CASE MIX

Het soort pathologie dat hier behandeld wordt is vrij eenduidig: ongeveer 70% van de patiënten heeft een lijden van de kransslagader. Dit wordt gecodeerd onder angina pectoris of instabiele angor. Ongeveer 20% van de patiënten heeft een kleppathologie. Het is belangrijk op te merken dat afsluiting van de kransslagader de oorzaak kan zijn van een acuut myocard infarct (AMI). Niet alle patiënten met angor of AMI worden geopereerd daar behandeling met medicijnen mogelijk is. Er bestaan criteria die bepalen of een operatie nodig is of niet. Kleppathologieën leiden altijd tot een operatie. Er is geen groot verschil tussen de verblijfsduur van patiënten met CABG en patiënten met een klepoperatie.
Andere pathologieën die soms voorkomen zijn: aneurysma, cardiomyopathie, hartdecompensatie en endocarditis. Patiënten met hypertensie komen niet voor. De

[10] In het uiteindelijk model hebben we dit soort van patiënten niet opgenomen.

hartchirurgen komen ook in aanraking met patiënten met ritmestoornissen voor zover pacemakers of defribrilatoren moeten geplaatst worden. Dit gebeurt echter op de 12 K12.

Een mooi voorbeeld van de complexiteit van het stochastisch patroon in het ziekenhuisproces is het volgende: 'Wanneer bij catheterisatie wordt gevonden dat een klepoperatie noodzakelijk is, wordt eerst de stomatologie geraadpleegd. Een klepoperatie mag immers nooit gebeuren wanneer 'een tandenkerkhof' aanwezig is omdat de infecties in de mond zich kunnen vastzetten op de hartklep'.

De soorten procedures die uitgevoerd worden op hartchirurgie worden vermeld in tabel 5.6. Ook wordt voor 1992 het aantal procedures weergegeven ([11]). Let wel één patiënt kan meerdere procedures ondergaan. Dus ongeveer de helft van de procedures zijn CABGs. Ongeveer een vijfde zijn klepoperaties. Een tiende van procedures wordt uitgevoerd op kinderen. Meestal betreft het hier aangeboren afwijkingen. Onder andere komt aneurysma (6 à 10 per jaar) voor. Vaatchirurgie (vasculaire procedures) gebeurt niet op hartchirurgie behalve wanneer één en dezelfde patiënt zowel een hartoperatie als een vaatoperatie nodig heeft. Maar dan nog wordt de vaatprocedure uitgevoerd door een vaatchirurg. Pacemakers worden meestal ingeplant in de pacemakerzaal op 12K12 (interne). Een recente innovatie is de ritmechirurgie. Dit gebeurt nog maar in beperkte mate (enkele per jaar).

[11]. Hierin zijn de revisies en de kleinere ingrepen niet ingbegrepen. Er zijn nog een 200 tot 25O additionele ingrepen. Revisies zijn altijd dringend. Dit zijn patiënten die nabloeden en moeten opengemaakt worden.

TABEL 5.6 ABSOLUUT EN RELATIEF AANTAL PROCEDURES UITGEVOERD IN 1992

SOORT PROCEDURE	AANTAL IN 1992	% van het totale aantal
Coronaire bypass (CABG)	425	49%
CABG + Klep	38	4%
Aortaklep	59	7%
Mitralisklep	33	4%
Dubbele klep	26	3%
Kind met kunsthart	65	7%
Kind zonder kunsthart	27	3%
Sternotomie met k.h.	9	1%
Sternotomie zonder k.h.	6	1%
Plaatsen I.A.B.P.	30	3%
Verwijderen I.A.B.P.	24	3%
Heringreep	42	5%
Andere	55	6%
WPW/Defribrillator	28	3%
harttransplantatie	5	1%
TOTAAL	871	100%

Tabel 5.7 geeft dus het diagnoseprofiel weer van de intensieve zorgen van de chirurgische eenheid (IE05). Tabel 5.8 geeft het diagnoseprofiel weer van de hospitalisatie-afdeling van de chirurgische eenheid (IA05). Opvallend is het overwicht van angina pectoris in beide eenheden. Op basis van deze steekproef worden de twee eenheden het best beschreven aan de hand van de ICD-9-CM codes 413, 395, 424 en 410. Op basis van deze tabellen kunnen reeds interessante dingen afgeleid worden. Bijvoorbeeld op IA05 is er een groep patiënten met 'overige acute en subacute vormen van ischemische hartaandoeningen' die op het eerste gezicht geen operatie ondergaan. Verdere studie is hier wel noodzakelijk.

TABEL 5.7 DIAGNOSEPROFIEL VAN IE05 OP BASIS VAN DE MVG GEGEVENS VOOR 1992

CODE	BESCHRIJVING	RELATIEVE DIAGNOSE VERDELING (%)
413	Angina Pectoris	64.91
395	Aandoeningen van de aortaklep	10.53
424	Overige aandoeningen van het endocard	8.77
410	Acuut Myocard Infarct	3.51
745	Congenitale afwijkingen van bulbus cordis en sluiting	3.51
394	Aandoeningen van de mitraalklep	1.75
428	Hartdecompensatie	1.75
441	Aneurysma van de aorta	1.75
519	Overige ziekten van de ademhalingswegen	1.75
998	Overige complicaties van verrichtingen, niet elders	1.75

* gegevens voor 72 patiënten die gedurende minstens één van de 20 door het ministerie geselecteerde dagen op IE05 aanwezig waren in 1992.

TABEL 5.8 DIAGNOSEPROFIEL VAN IA05 OP BASIS VAN DE MVG GEGEVENS VOOR 1992 (1)

CODE	BESCHRIJVING	RELATIEVE DIAGNOSE VERDELING (%)
413	Angina Pectoris	61.11
411	Overige acute en subacute vormen van ischemische hartaandoeningen	9.60
395	Aandoeningen van de aortaklep	6.57
424	Overige aandoeningen van het endocard	6.06
428	Hartdecompensatie	3.54
394	Aandoeningen van de mitraalklep	3.03
998	Overige complicaties van verrichtingen, niet elders	2.02
410	Acuut Myocard Infarct	1.01
730	Osteomyelitis, periostitis en overige infecties van...	1.01

* (1) Ongeveer 6% van de patiënten is niet opgenomen omdat ze verdeeld zijn over een te groot aantal diagnoses (12 codes met een relatieve waarde van 0.51)

* gegevens voor 200 patiënten die gedurende minstens één van de 20 door het ministerie geselecteerde dagen op IA05 aanwezig waren in 1992.

Patiënten met hartinfarct of angor zijn kandidaten voor een CABG. Bij een acuut myocard infarct wordt tot CABG operatie overgegaan als de operatie kan gebeuren binnen de 4 uur. Anders wacht men een aantal weken om het hart te laten bekomen. Meestal wordt wel een catheterisatie (eventueel met dilatatie) gedaan op basis waarvan men een besluit neemt. Meestal gaat de patiënt naar huis en wordt er een operatie gepland. Ondertussen kan de patiënt echter weer opgenomen worden met angor. Dit impliceert dat het weinig gebeurt dat AMI patiënten binnen eenzelfde verblijf geopereerd worden.

De uitslag van de coronarografie is dus zeer belangrijk om te bepalen welke behandeling men zal volgen. Een behandeling met medicatie is dus ook mogelijk. De criteria die bepalen of een operatie nodig is, steunen op de belangrijkheid van de coronairen die verstopt zijn (hoofdstam of niet) en de omvang van de aantasting (het percentage vernauwing). Een 85% vernauwing van een hoofdstam is dus een indicatie om zo vlug mogelijk te opereren. Ook het aantal vernauwingen speelt een rol. Twee vernauwingen op een hoofdstam kunnen een indicatie zijn voor operatie.

Het is belangrijk op te merken dat in de meeste gevallen een coronarografie en een hartoperatie niet gebeuren gedurende één verblijf. Meestal gaan de patiënten na coronarografie naar huis en wordt er een hartoperatie gepland. Enkel wanneer het een hoofdstam betreft en de patiënt in levensgevaar is, blijft de patiënt in het ziekenhuis. Meestal worden dergelijke patiënten wel op hartchirurgie opgenomen. Patiënten die gepland worden, worden op een later tijdstip opgenomen met een zeer duidelijke diagnose. Wat eventueel kan gebeuren is dat een overbrugging voorzien is, en dat vastgesteld wordt dat de klep ook verkalkt is.

5.2.2. DE FLOW

De patiënten van hartchirurgie komen meestal toe op de hospitalisatie-afdeling (van hartchirurgie, IA05), verhuizen daarna naar het operatiekwartier (IE05), komen dan terecht op Intensieve Zorgen (hartchirurgie), en keren daarna terug naar de hospitalisatie-afdeling. Soms komen de patiënten na IZ terecht op de midcare afdeling die fysiek gelegen is op de hospitalisatie-afdeling.

De meeste patiënten die hier geopereerd worden, hebben een hartcatheterisatie ondergaan. Dit is zeker het geval bij CABG (overbrugging) en hartklepprocedures. De catheterisatie gebeurt altijd met opname op hart- en vaatziekten. Normaal gaan patiënten na catheterisatie naar huis. Indien een operatie noodzakelijk is, wordt er één gepland voordat de patiënt vertrekt (in samenspraak met de cardioloog en de hartchirurg). In een aantal gevallen (15% tot 20%) mag de patiënt echter niet naar huis (meestal in geval van instabiele angor die bijzonder dicht bij infarct staat vooral doordat een hoofdstam is aangetast of bij bejaarde mensen). In deze gevallen wordt de patiënt meestal overgebracht naar de Intensieve Zorgen (12K12) en verblijft daar totdat de operatie doorgaat. Als de patiënt in een meer stabiele toestand is, kan hij terechtkomen op een hospitalisatie-afdeling (hartchirurgie of hart- en vaatziekten). De operatie gaat meestal door binnen de week of zelfs binnen de twee dagen.

De meeste patiënten komen dus van thuis wanneer ze opgenomen worden op IA05 (vaak verwezen door cardiologen van andere ziekenhuizen). Er komen ook patiënten van andere ziekenhuizen.
Er komen ook soms patiënten van de cardio-hospitalisatie. Soms (1% van de gevallen) komen ze via spoedopname. Dit is enkel bij heropnames omwille van wondinfecties. Spoedopnames zijn zeldzaam omdat de geneesheer meestal rechtstreeks naar de chirurg belt, die de patiënt laat binnenkomen op de afdeling. Patiënten van 12K12 gaan meestal rechtstreeks naar het operatiekwartier en komen dus pas na operatie naar IA05. Enkel wanneer 12K12 volzet is, kan het gebeuren dat iemand rechtstreeks op de midcare komt. Er zijn ook een aantal patiënten die dus rechtstreeks opgenomen worden op de IZ hartchirurgie en pas na de operatie naar de afdeling komen. Er komen nooit patiënten van de catheterisatiezaal. Wel gaan er patiënten van catheterisatiezaal naar operatiekwartier. Dit zijn de echte urgente (meestal in aansluiting met een ballondilatatie die mislukt).

Patiënten die rechtstreeks van huis komen voor een geplande operatie, worden 2 dagen voor de operatie opgenomen (dag -2).
Op de dag van opname (dag -2), wordt een kamer aangewezen, het verloop van de operatie toegelicht en de vermoedelijke verblijfsduur gegeven. Op dag (-1) worden de onderzoeken gedaan. Dag 0 is dan de dag van operatie.
Er zijn twee operatiezalen die parallel werken. 90% van de patiënten komen van de hospitalisatie-afdeling hartchirurgie. De urgente komen meestal van cathlab; sommige semi-urgente komen van intensieve zorgen (zowel hartchirurgie als 12K12)([12]). Soms komen er

[12]. De patiënten die van IZ hartchirurgie komen, zijn meestal patiënten die pre-operatieve observatie nodig hebben van de hartchirurgen. Op 12K12 komen patiënten terecht die na een catheterisatie in een te onstabiele toestand zijn.

patiënten van hart- en vaatziekten rechtstreeks naar OK als er geen plaats meer is op 5K12 IA.([13]) Vanaf 7.50 uur wordt de eerste patiënt (1 per operatiezaal) voorbereid voor operatie (anesthesiologie gebeurt in de operatiezaal zelf). Om 8.00 uur kan de operatie starten. Een operatie duurt gemiddeld 4 uur. Rond de middag wordt de tweede patiënt naar het OK gebracht.

Na de operatie wordt de patiënt op zijn minst voor 1 dag overgebracht naar Intensieve Zorgen Hartchirurgie. Alle patiënten gaan van OK naar IZ (enkele de hele lichte ingrepen kunnen hierop een uitzondering maken). 95% van de opnames op IZ komen rechtstreeks uit de operatiezaal in hartchirurgie. 5% van de patiënten komen van de afdeling (dit is dan echter wel meestal pre-operatief voor onstabiele patiënten die op een operatie wachten). Hier zijn er 6 bedden, uitgerust voor intensieve monitoring. Men heeft twee nieuwe geïsoleerde ruimten gemaakt voor IZ (nog niet in gebruik). De tweede dag na de operatie (dag 2) wordt de patiënt meestal overgebracht naar de hospitalisatie-afdeling in een 'gewoon' bed of in een 'midcare' bed ([14]). 3/4 van de patiënten gaan naar de midcare; 1/4 gaat rechtstreeks naar de kamer ([15]). Het zijn vooral patiënten die meer nodig hebben dan de gewone telemetrie die op de midcare terechtkomen. De wijze waarop de patiënt een operatie doorgemaakt heeft, bepaalt meestal of deze patiënt op de midcare terecht komt of niet. Leeftijd speelt geen rol. Patiënten blijven gewoonlijk maar een dag op de midcare en komen dan naar de kamer. Dan gaat alles tamelijk vlug: kinesietherapie wordt gestart, patiënten staan al op, gaan naar de dagzaal.
Op dag (5), (7) en (8) moeten er onderzoeken gebeuren. De negende dag na de operatie gaan de patiënten gewoonlijk naar huis, tenzij er complicaties optreden. De meest voorkomende complicaties zijn wondproblemen en ritmestoornissen. Er zijn patiënten die enkele maanden in het ziekenhuis verblijven.
De meeste patiënten gaan naar huis. Sommige patiënten vragen herstellingsoorden aan. Er zijn ook patiënten die naar hun ziekenhuis willen terugkeren. Er worden heel weinig patiënten getransfereerd naar andere specialismen binnen het ziekenhuis (bv. geriatrie). Op twee jaar zijn er op de afdeling nog maar 5 overlijdens geweest.

De flow is niet fundamenteel verschillend voor overbruggingen en klepoperaties.

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[13]. De herkomst van de patiënt is in die zin belangrijk dat de transporttijd kan verschillen en dat de afwerking van de patiënt langer kan duren.

[14]. Kinderen blijven normaliter langer op IZ. Ze worden daarna naar de kinderafdeling gebracht.

[15]. Het betreft hier enkel volwassenen. Kinderen gaan immers naar de kinderafdeling (zie verder).

De beperkende factor in deze flow blijkt vooral IZ en de afdeling te zijn (te weinig bedden). Er moet gewezen worden op het feit dat de flow volledig ondersteund wordt door de structuur van de afdelingen. Zowel cathlab als IZ liggen vlak naast de operatiezalen. Op dezelfde verdieping, maar in een andere vleugel bevindt zich de hospitalisatie hartchirurgie. Deze structuur is van groot belang bij eventuele urgenties. Hierna worden de hospitalisatie-afdeling, het operatiekwartier en de intensieve zorgen hartchirurgie meer in detail besproken

5.2.3. DE HOSPITALISATIE-AFDELING (IA05)

Op het einde van de week (donderdag) krijgt hospitalisatie een lijst met de namen van alle patiënten die moeten geopereerd worden gedurende de volgende dagen. Ze maken daarbij vooraf afspraken voor bepaalde testen voor deze patiënten: een foto van de longen, echografie van het hart en een doppler-carotide. Patiënten komen dus maar twee dagen voor hun operatie binnen. De bovenstaande testen moeten gebeuren gedurende deze twee dagen. De patiënten die opgenomen worden, hebben gewoonlijk een diagnose.

De avond voor de operatie wordt medegedeeld wie als eerste patiënt de volgende dag zal geopereerd worden. De andere patiënten worden telefonisch opgeroepen. Patiënten worden dan door de verpleegkundigen zelf naar het OK kwartier gebracht (de patiënt heeft immers premedicatie gehad).

De gemiddelde verblijfsduur is 9 dagen na operatie. Soms blijven patiënten langer. Met uitzondering van patiënten met wondproblemen blijft er nooit iemand langer dan 14 dagen. Omwille van de grote turnover gaan de patiënten dan vaak terug naar de kliniek van de cardioloog die hen gestuurd heeft, ofwel gaan er patiënten naar een bepaalde hersteloord. De sociale dienst regelt het zo dat deze patiënten rechtstreeks naar de hersteloord kunnen gaan. Wondproblemen kunnen dus de verblijfsduur verlengen. Risicofactoren in dit verband zijn dan vooral (1) zwaarlijvigheid, en (2) diabetes. Ook roken is een risicofactor.

De gemiddelde leeftijd op de hospitalisatie-afdeling is ongeveer 60 jaar. Jongere patiënten zijn meestal de meer urgente.
Het is ook opmerkelijk dat de laatste jaren steeds meer vrouwen opgenomen worden voor operatie (de helft vrouwen en de helft mannen). De leeftijd oefent geen invloed uit op de verblijfsduur.

Op hospitalisatie zijn er in totaal 29 bedden, waarvan 4 midcare bedden. Er zijn twee speciale eenpersoonskamers voorzien voor harttransplantatie en besmette patiënten. Er zijn hiernaast nog drie eenpersoonskamers. Soms worden patiënten gehospitaliseerd op andere verdiepingen: de 6K12, de 8K12 en Intensieve Zorgen (12K12). Benaderend zijn dit 3 patiënten per week die op 'pool' verdiepingen terechtkomen en 3 patiënten die op IZ terechtkomen.
Dit is enkel pre-operatief; dus nooit postoperatief. De patiënten die op 12K12 liggen worden meestal rechtstreeks naar het operatiekwartier gebracht. Patiënten op de andere afdelingen worden (indien mogelijk) een of twee dagen voor de operatie naar hartchirurgie gebracht.
De bezettingsgraad is in de 80%. Doordat er op zaterdag en zondag niet veel geopereerd wordt, loopt de midcare in het begin van de week niet altijd vol. Dit wordt min of meer bevestigd op basis van de MVG registratiegegevens voor 1992.
Er zijn te weinig bedden op de afdeling (vooral op de 'gewone' kamers). Hierdoor moeten patiënten soms vroeger naar huis gestuurd worden. Een gevolg is ook dat de patiënt pre-operatief vaak op een andere afdeling terecht komt. Idealiter zou de patiënt op hartchirurgie moeten opgenomen worden.
De afdeling werkt met dubbele bezetting. Van zodra iemand naar de operatiezaal gebracht wordt, wordt zijn bed vrijgemaakt voor een andere patiënt. De patiënt die echter naar de operatiezaal gebracht is, komt echter terug. Indien de afdeling dan volzet is, kan het gebeuren dat pre-operatieve patiënten op een poolafdeling gelegd worden. Dit gebeurt echter heel zelden. Het kan ook uitzonderlijk gebeuren dat een patiënt iets langer op de midcare of op IZ blijft liggen.
Wanneer er plaats vrijkomt op de hospitalisatie-afdeling en er liggen patiënten op 'pool' afdelingen, dan worden die getransfereerd naar de hospitalisatie-afdeling.

Op de hospitalisatie-afdeling werken 20.5 FTE verpleegkundigen (incl. hoofdverpleegkundige, 3/4 ziekenhuishelpster en een 1/2 secretaresse). Iets minder gegradueerden dan gebrevetteerden. Ze doen hetzelfde werk. De werklast voor verpleegkundigen is hoog gedurende het weekend (er zijn dan minder mensen aanwezig; de hoofdverpleegkundige, de secretaresse en de ziekenhuishelpster werken normaal alleen in de week).
Tabel 5.9. toont een aantal gegevens over de werklast van verpleegkundigen op IA05 op basis van de MVG registratie-gegevens. Het is belangrijk deze gegevens te gaan vergelijken met bijvoorbeeld de werklast van andere verpleegeenheden (bijvoorbeeld de IZ hartchirurgie).

TABEL 5.9. GEGEVENS I.V.M. DE VERPLEEGKUNDIGE WERKLAST OP IA05

	09/92 (1)	12/92	03/93
totaal uren (2)	1543	1463	1396
# patiënten (3)	53	54	61
# pat/dag (4)	26	26	31
# uren/dag/pat(5)	3.95	3.75	3.00
totaalwaarde (6)	12773.25	18410.75	21124.50
patiëntenindex(7)	241.00	340.94	346.30
werklastindex (8)	8.28	12.58	15.13

(1) voor elk van deze maanden worden de eerste 15 dagen in beschouwing genomen
(2) dit is het totaal aantal verpleeguren exclusief de uren leerlingen over de 15 dagen
(3) dit is het totaal aantal patiënten over de 15 dagen
(4) dit is het aantal patiënten per dag of het totaal aantal patiënten die in de steekproef van 15 dagen opgenomen is gedeeld door 15
(5) dit is het totaal aantal uren/15 dagen/aantal patiënten per dag
(6) dit is de totaalwaarde van de MVG registratie gewogen aan de hand van PRN-punten
(7) dit is de totaalwaarde gedeeld door het aantal patiënten
(8) dit is de totaalwaarde gedeeld door de totale aantal uren verpleegkundig personeel.

Overbelasting van het personeel wordt meestal intern opgevangen. Soms wordt beroep gedaan op verpleegkundigen van andere afdelingen.

Er zijn 4 vaste stafleden en twee assistenten.

In de midcare is er een belangrijke monitoring-uitrusting. Er zijn ook 3 tot 4 kamerpatiënten met telemetrie (volgen van hartritme). Patiënten die nood hebben aan telemetrie moeten wel op de afdeling blijven, maar kunnen in om het even welke kamer gelegd worden ([16]).

Belangrijke klinische ondersteunende diensten zijn: bloedafnames door laboratorium, foto van de longen (3 tot 4 maal na operatie) door radiologie, echografie van het hart op poli-cardio, en een revalidatiegesprek met de sociale verpleegster.
De laboresultaten komen met de printer naar de afdeling. De prioriteiten worden 's morgens vroeg afgeprikt en de resultaten zijn binnen om 10 uur. De resultaten van niet-prioritaire testen komen in de late namiddag binnen. Er moet nooit gewacht worden op labo-testen. Thoraxen (radiologie) moeten niet afgesproken worden als het binnen de uren is (8.00 -17.00). Nadien is het iets moeilijker. Voor een echografie wordt een afspraak op een bepaalde datum vastgelegd.

[16]. Een telemetrie is een toestel dat aangelegd wordt aan de patiënt. Het werkt op batterijen en heeft een zender.

Het gebeurt heel zelden dat een echografie niet kan geboekt worden op de voorafgestelde datum. Normaal gezien moet op dag 7 een echografie gebeuren. Op dag 8 of dag 9 heeft het gesprek met de sociale verpleegster plaats.

Professor Van Nooten heeft lijsten opgesteld over wat in de medicijnenkast moet zitten. Het gebeurt zelden dat ze iets niet in stock hebben. Als stockbreuk voorkomt, kan toevlucht gezocht worden op IZ.

De hoofdverpleegkundige doet het materiaalbeheer. Bestellingen gebeuren op vrijdag en op dinsdag komt het materiaal toe. De voeding wordt bij opname onmiddellijk ingebracht (op de computer). Daar men weet wanneer de patiënt zal geopereerd worden, kan voor de desbetreffende dagen de voeding ook onmiddellijk afgezegd worden. Het zijn wel bijna allemaal dieetpatiënten. Dit is een voordeel. Niet-dieet patiënten hebben immers een keuze tussen menu's. Dit moet elke dag gevraagd worden.

5.2.4. HET OPERATIEKWARTIER

Een belangrijk onderdeel van hartchirurgie zijn de operatiekamers. Er zijn twee operatiezalen. Die worden bemand vanaf 7.30 uur. De eerste ingreep wordt voorzien om 8.00 uur. De patiënt moet om 7.50 uur op de operatietafel liggen. Er is dus een voorbereidingsfase van 20 minuten. Het personeel werkt in feite tot 20.00 uur 's avonds. Er is een ploeg van 7.30 uur tot 16.00 uur, en een ploeg 12.00 tot 20.00 uur die in aansluiting wachtdienst doet. Die doen de (eerste) wacht tot 7.30 uur 's morgens ([17]). Er is 1 persoon die werkt van 9.00 uur tot 18.00 uur en die doet de vierde wacht (die kan enkel opgeroepen worden tot 24.00 uur). Deze personen blijven meestal langer en moeten bijna niet terugkeren.

Het personeel wordt meestal na 18.00 uur opgeroepen voor revisies (nabloedingen) of voor dringende procedures. Harttransplantaties vallen ook altijd buiten de normale uren.

De operatiezalen zijn dus bezet van 8.00 uur 's morgens tot 18.00 en later. Het gebeurt slechts uitzonderlijk dat op een bepaalde morgen of namiddag geen operatie gepland is. Dit gebeurt als er maar 3 operaties worden ingepland.

Bij het uitvoeren van een catheterisatie (zeker in het geval van dilatatie) kan het gebeuren dat dringend een ingreep noodzakelijk is. Daarom wordt er slechts gedilateerd als er een operatiezaal vrij is.

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[17]. Wachtdienst betekent dat die persoon bereikbaar moet zijn. Hij is dus niet aanwezig.

Er werken 12,5 FTE op het operatiekwartier (d.i. 13 verpleegkundigen, inclusief de hoofdverpleger). Een mengeling van A1 en A2 verpleegkundigen die hetzelfde werk doen. Er zijn twee groepen: de ene groep zijn verpleegkundigen die vooral de anesthesisten meehelpen; de andere groep helpt de chirurgen mee als instrumentiste. Van de 12 verpleegkundigen zijn er 3 typische anesthesie-verpleegkundigen en 9 instrumentisten.
Er is ook een perfusiedienst. Er zijn 3 perfusionisten. Dit zijn de verpleegkundigen die de hart/long machines bedienen. Die hebben een zeer specifieke taak (alles wat extra-corporele circulatie aangaat).
Er zijn drie verpleegkundigen per zaal voorzien. Vanaf 16.00 uur valt men terug op 2 personen. Een van hen is de omloopverpleegkundige. Die is in de zaal tijdens de ingreep. Zij/hij moet van alles aanbrengen, van alles voorzien.
De werklast is hoog door de frequentie van de wachtdienst en het aantal uren dat men moet presteren in die wachtdienst (Er zijn 3 weken wachtdienst op 8 weken: 1 week vierde wacht en 2 weken eerste wacht). Omdat vroeger te veel overuren (± 4000 overuren per jaar) gepresteerd werden, werd een nieuw roulement geïnstalleerd. Dit roulement blijkt minder overuren te genereren.

Er is ook een verpleeghulp (sanitair helpster) die vooral het stockbeheer doet: ze doet de bestelling van al het dagelijks materiaal. Ze onderhoudt ook de operatietafel. Ze werkt onder supervisie van de verpleegkundigen.

Er zijn 4 chirurgen (waarvan één chirurg in opleiding). Er komen ook 2 assistenten werken voor 3 tot 6 maanden van de dienst algemene heelkunde.

Belangrijke uitrusting zijn de operatietafel, de monitoren, beademingstoestel, coagulatietoestel, de pompen voor de extra-corporele circulatie.

Het operatiekwartier heeft zijn eigen labo (bloedgassen).Nu en dan moeten er bloedstalen naar een ander labo gebracht worden. Men heeft ook ondersteuning van de bloedbank. Er is een eigen plasma-reservoir.

Een belangrijk niet-klinische ondersteunende dienst is het materiaalbeheer. De stock is echter zeer groot zodanig dat er weinig problemen optreden. De grote stock kan vermeden worden indien de apotheek automatisch de stock zou aanvullen. Stocks worden nu enkel op bestelling aangevuld. Het OK en IZ zijn de twee grootste afnemers van medisch materiaal. Medisch

materiaal omvat dus zowel datgene dat op naam van de patiënt besteld wordt, en alles dat in de ligdagprijs zit.
De instrumenten worden behandeld door de centrale sterilisatie. Soms moet er wel bijbesteld worden. Er wordt niets meer op de afdeling gesteriliseerd.
De planning van de operaties gebeurt volledig onder leiding van de hartchirurgen. Het gebeurt manueel. Een cardioloog/hartchirurg telefoneert naar de secretaresse van de dienst hartchirurgie om na te gaan of een bepaalde operatie op een bepaalde dag kan doorgaan. De secretaresse noteert dit in een agenda. Meestal kan de ingreep binnen de 3 weken ingepland worden. Er is dus geen echte wachtlijst. Als er geen plaats is en de ingreep is dringend, wordt het advies van de hartchirurgen gevraagd. Het is bijvoorbeeld mogelijk dat een andere operatie dan wordt uitgesteld. Planningen gebeuren soms lang op voorhand. Bijvoorbeeld op 8 september 1993 was alles reeds volgeboekt tot de eerste vrijdag van oktober. Per dag worden in de regel 3 à 4 ingrepen gepland (2 ingrepen per operatiezaal). Er wordt ook rekening gehouden met de aard van de operaties (om te vermijden dat 4 enorm zware operaties op dezelfde dag gepland worden). De woensdag worden minder operaties gepland omdat de dokters dan hun patiënten poliklinisch ontvangen. Kinderoperaties worden wel iets langer op voorhand gepland.

Soms zijn er echte urgenties op de dag zelf. Meestal komen die patiënten van de cathlab. De aneurysma patiënten zijn ook meestal urgent. Er moet ook rekening gehouden worden met de procedures, uitgevoerd op cathlab, maar waarbij de standby van een operatiezaal gevraagd wordt. Dit is natuurlijk belastend voor het operatiekwartier. Dit zijn vooral patiënten met een acuut hartinfarct (binnengestuurd via de spoedopname of via andere ziekenhuizen), dilatatie-patiënten of patiënten die een laser-procedure moeten ondergaan. Een dergelijke procedure wordt dan voorzien tegen dat een zaal zal vrijkomen. Hun procedure start dan op het moment dat de patiënt de zaal verlaat. Eventueel moet dan wel eventjes gewacht worden.

Het operatieplan wordt wekelijks doorgestuurd naar de hospitalisatie-afdeling zodat bedden kunnen gepland worden. De dag voor de feitelijke operaties worden de geplande operaties op een OK bord in het secretariaat genoteerd. Er wordt vermeld welke patiënt het betreft, de soort operatie, wie de chirurg is en wie de anesthesist is. De geneesheren kunnen deze planning wijzigen.

De gemiddelde duur van een operatie bedraagt 4 uur. De duur wordt vooral bepaald door de aard en complexiteit van de ingreep en de toestand van het ventrikel (de injectiefractie). Tabel 5.10 geeft enkel voorbeelden van verschillende soorten ingrepen en een benaderende duur. In deze tijden zit wel de inductietijd voor anesthesie inbegrepen (± 45 minuten). Operatietijden zijn moeilijk te bepalen omdat zoveel factoren deze tijden beïnvloeden. In de planning wordt geen rekening gehouden met de duur van een operatie. Er wordt enkel rekening gehouden met een ratio (3 of 4 patiënten per dag).

TABEL 5.10 VOORBEELDEN VAN PROCEDURES EN HUN GEMIDDELDE DUUR

PROCEDURE	GEMIDDELDE DUUR
1 of 2 bypassen	± 4 uur
4 of 5 bypassen	± 5 uur
Enkelvoudige klep	± 4 uur
Meervoudige klep	± 4 + 1/2 uur bij per klep
Combinatie bypass en klep	± 5,5 uur

Het is dus geen geautomatiseerd systeem. Er worden geen statistieken bijgehouden op de afdeling. De directie nursing zou wel studies ondernomen hebben over het verband tussen het soort operatie en de tijd nodig voor een dergelijke operatie.

5.2.5. DE INTENSIEVE ZORGEN HARTCHIRURGIE

95% van de patiënten komen uit de operatiezaal. 5% van de patiënten komen van de IZ (12K12), spoedopname,.... Deze patiënten mogen niet besmettelijk zijn. Er wordt gepoogd om in dit geval patiënten met een gelijkaardige pathologie op te nemen: bijvoorbeeld een infarct patiënt. Deze patiënten kunnen wel eens een catheterisatie nodig hebben maar dit gebeurt weinig.
Alle patiënten met een primaire operatie passeren via IZ. Bij revisies (bv. omwille van wondproblemen en andere verwikkelingen) komt de patiënt niet altijd op IZ.

Een voorbeeldje van de flow van de patiënt doorheen IZ: een patiënt die in de voormiddag geopereerd wordt, komt dan naar IZ. Ze wordt op IZ gestabiliseerd, moet wakker worden om spontaan te gaan ademen, moet bekomen van de emotie. In de voormiddag van de volgende dag verlaat de patiënt dan IZ. 3/4 van de volwassen patiënten gaan naar de midcare. 1/4 ervan gaat rechtstreeks naar de kamer op hospitalisatie hartchirurgie. De kinderen gaan naar de kinderafdeling (meestal naar de kamer, niet naar IZ). Het gebeurt heel zelden (± 1 patiënt per maand) dat patiënten na stabilisatie op IZ hartchirurgie overgebracht worden naar IZ (12K12) omdat er plaats nodig is voor een andere patiënt en er geen plaats meer is op de midcare. Let wel: patiënten die geopereerd zijn en op 12K12 terechtkomen, blijven chirurgische patiënten (onder de bevoegdheid van de chirurgen). 1 à 3 % van de patiënten overlijden. De mortaliteit ligt het hoogst bij de pasgeboren baby's.

Patiënten blijven gemiddeld 24 uren op IZ. Dit verblijfsduur is wel gedaald door het in werking stellen van de midcare sinds september 1993. Voordien bleven patiënten 48 uur op IZ.

Er is geen verschillend patroon in verblijfsduur op IZ naargelang van het soort procedure (kleppathologie of CABG). De kinderen (congenitale afwijkingen) hebben een zodanig complexe pathologie dat ze wel een week op IZ kunnen verblijven. Sterk onstabiele patiënten (meestal met een meervoudige diagnose) kunnen soms ook langer op IZ blijven. De leeftijd speelt geen rol in de gemiddelde verblijfsduur.

Het in gebruik nemen van de midcare op de hospitalisatie-afdeling heeft het patiëntenpatroon van IZ volledig gewijzigd. Ze hebben nu nog enkel eerste dag post-op patiënten. Dit zijn de zwaarste patiënten. Deze patiënten zijn nog heel onstabiel, liggen nog aan beademing en moeten nog wakker worden. Eens wakker gaan de patiënten weg uit IZ. Dit zorgt ook voor een grote turnover. De werklast is bijgevolg toegenomen zowel qua intensiteit als qua volume.

IZ heeft op dit moment 6 bedden. Vanaf oktober 1993 worden twee nieuwe bedden geopend. Deze bedden zijn twee afzonderingskamers bestemd voor transplantatie. Van de 6 bedden zijn er 4 gewone bedden voor volwassenen en 2 kinderbedden (isolatie-kamers). Op deze plaatsen kunnen echter ook volwassenen gelegd worden. De bezettingsgraad van de bedden is 92%. Hierin moet verrekend worden dat tijdens het weekend de IZ niet volledig bezet is. Dit betekent dat tijdens de week een bezetting wordt bereikt van soms meer dan 100%. Dit betekent dat er soms een zevende bed moet worden toegevoegd. IZ Hartchirurgie blijkt dus een belangrijk knelpunt te zijn in de doorstroming van patiënten: 4 operaties per dag en maar 6 IZ bedden levert een grote turnover.

Wanneer een patiënt uit OK komt, en er is geen plaats op IZ, dan kan hij nog eventjes op OK blijven (dit gebeurt de laatste tijd meer en meer; voor 1 of maximum 2 uren). Dan wordt er gezocht of er een patiënt (op IZ) naar de midcare of de afdeling kan gaan. Een operatie duurt ook 4 à 5 uur. Dus er kan op tijd ingegrepen worden. Wanneer bezettingsproblemen optreden, heeft dit vaak te maken met de doorstroming van patiënten naar midcare en vandaar naar de kamer. Er is ook het probleem op de afdeling dat een patiënt maar na half drie het ziekenhuis mag verlaten, maar dat IZ voor half drie plaats nodig heeft.

Indien de bovenstaande procedures geen plaats opleveren, dan wordt er een bed toegevoegd. Dit wordt echter niet aangeprezen.

De IZ werken met 22 mensen, gelijk aan 18 FTE. Er zijn enkel 2 gebrevetteerden. Die voeren dezelfde taken uit als de geaggregeerden. Er is nog een ziekenhuishelpster, een hoofdverpleegkundige en een secretaresse (3/4).

De verpleegkundigen werken in drie shifts van respectievelijk 4, 4 en 3 (nachtdienst) personen. Dit is de norm. Soms moet men met 3 respectievelijk 2 mensen werken.
De verpleegkundigen hebben een grote werklast. De intensieve en continue observatie van de patiënten veroorzaakt deze grote werklast. Tijdens de eerste uren post-op is het nauwelijks haalbaar om twee patiënten tegelijkertijd te observeren. De verzorging is dus ondergeschikt op observatie. Kinderen verzwaren nog meer de werklast.
Tabel 5.11. toont een aantal gegevens over de werklast van verpleegkundigen op IE05 op basis van de MVG registratiegegevens. Het is belangrijk deze gegevens te gaan vergelijken met bijvoorbeeld de werklast van andere verpleegeenheden (bijvoorbeeld de IA05).

TABEL 5.11. GEGEVENS I.V.M. DE VERPLEEGKUNDIGE WERKLAST OP IE05

	03/92 (1)	06/92	09/93	12/92
totaal uren (2)	1285	1458	1219	1514
# patiënten (3)	39	34	37	39
# pat/dag (4)	7	7	8	8
# uren/dag/pat(5)	12.2	13.9	10.15	12.6
totaalwaarde (6)	17866.25	22405.25	21952.25	21257.50
patiëntenindex(7)	458.11	658.97	593.30	545.06
werklastindex (8)	13.90	15.37	18.01	14.04

(1) voor elk van deze maanden worden de eerste 15 dagen in beschouwing genomen
(2) dit is het totaal aantal verpleeguren exclusief de uren leerlingen over de 15 dagen
(3) dit is het totaal aantal patiënten over de 15 dagen
(4) dit is het aantal patiënten per dag of het totaal aantal patiënten die in de steekproef van 15 dagen opgenomen is gedeeld door 15
(5) dit is het totaal aantal uren/15 dagen/aantal patiënten per dag
(6) dit is de totaalwaarde van de MVG registratie gewogen aan de hand van PRN-punten
(7) dit is de totaalwaarde gedeeld door het aantal patiënten
(8) dit is de totaalwaarde gedeeld door het totaal aantal uren verpleegkundig personeel.

De tabellen 5.9 (IA05) en 5.11 (IE05) geven duidelijk aan dat de beide eenheden qua zorgenbehoefte volledig verschillend zijn: het gemiddeld aantal verpleeguren per dag en per

patiënt op de hospitalisatie-afdeling is 3.5 uur; op de intensieve zorgen is dit 12 uren. De werklastindex blijkt nochtans op het eerste gezicht niet fundamenteel te verschillen. Dit wil zeggen dat de grotere zorgbehoefte opgevangen wordt door meer FTEs per patiënt.
Bij overbelasting van het personeel wordt eerst zelf een oplossing gezocht. Daarna is het mogelijk dat personeel van andere IZ bijspringt. Maar de taakomschrijving is echter zo gespecialiseerd op hartchirurgie dat iedereen niet zomaar kan ingezet worden.

Op intensieve zorgen (IE05) is er wel een merkwaardig fenomeen vast te stellen op basis van de MVG registratiegegevens. Het aantal verpleegkundigen dat op ieder van de dagen van de registratie werkte was relatief constant onafhankelijk van het feit of er nu 1 of 10 patiënten op die dag op IZ lagen. Dit moet verder bestudeerd worden.

De nachtdienst op IZ is geen 'waakdienst'. 's Nachts moet dezelfde opdracht uitgevoerd worden als overdag. Naast verpleegkundigen, blijft ook altijd een artsanesthesist aanwezig.

De monitor-uitrusting is van groot belang. Hierop wordt het hartritme gevolgd, de arteriële bloeddruk, de intraveneuze druk en het zuurstofgehalte, enz. gemeten. De observatie van de monitor door mensen is van even groot belang als de 'mechanische' observatie door de monitor. De beademingstoestellen zijn ook van groot belang.

IZ doet beroep op de volgende klinische ondersteunende diensten: klinisch labo, de radiologie, de biotechnische dienst. Er wordt weinig beroep gedaan op de poli cardiologie. Er zijn wel problemen met de geautomatiseerd link met het labo: printer die niet werkt,.... Die infrastructuur staat niet op punt. Hierdoor komen uitslagen soms te laat. Een therapie is meestal afhankelijk van wat men op papier ziet (en van de observatie). Het hoeft geen betoog dat die link van groot belang is. Het gebeurt echter niet dat een patiënt langer op IZ moet blijven omwille van het te laat zijn van een bepaald testresultaat. IZ beschikt zelf ook over een bloedgasanalyzer. Op basis hiervan kan reeds actie ondernomen worden.
In de radiologie beschikt de IZ over een voorkeurbehandeling in die zin dat 's morgens eerst hun foto's worden gemaakt en deze foto's dan eerst geprotocolleerd worden. Overdag is er altijd een technicus beschikbaar die met een mobiel radiologietoestel ter plaatse komt.

Niet-klinische ondersteunende diensten van groot belang zijn o.m. de bloedbank. Materiaalbeheer is ook van belang. Dit is de taak van de hoofdverpleegkundige. Uiteindelijk moet er een klimaat gecreëerd worden waarbij verpleegkundigen niet van het bed weg moeten.

Alles moet rond het bed gestockeerd worden. De ziekenhuishelpster houdt hier een oogje in het zeil.

APPENDIX 7

THE BILL OF RESOURCE FOR DRG 104, DRG 105, DRG 106 AND DRG 107

APPENDIX 7 THE BILL OF RESOURCES FOR DRG 104, DRG 105, DRG 106 AND DRG 107

In the following table, we list the bill of resources for the DRG 104, 105, 106 and 107. The following resources are taken into consideration: beds (LOS in hours), echography (ECHO), electrocardiogram (EKG), physiotherapy (FYSIO), chest X-rays (RX) and catheterisation (CATH). Each of these resources are expressed in terms of number of units (e.g. number of chest X-rays).The number of resources consumed by the DRG patients are registered for three stages: postoperative (POST), preoperative (PRE) and surgical (SURG). Thus the row EKGPOST shows the parameters for the number of electrocardiograms delivered to the patients while residing in the postoperative stage. The development of the bill of resources is described in the main text in section 3.2.2.1. The structuring of a bill of resources. The following statistics are considered: mean, median, minimum, maximum, lower quartile, upper quartile, quartile interval and the standard deviation.

Table The bill of resources for DRG 104

BILL OF RESOURCES FOR DRG 104									
CASENAME	N	MEAN	MEDIAN	MIN	MAX	LOWQUA	UPQUA	QUARTILE	STD_DEV_
LOSPOST	38	321,58	242,5	0	1132	195	365,5	170,5	234,35
LOSPRE	38	206,53	180	47	666	99	267	168	131,24
LOSSURG	38	60,79	50	1	378	28	70	42	60,75
ECHOPOST	38	1,18	1	0	3	1	1	0	0,73
ECHOPRE	38	1,55	2	0	3	1	2	1	0,72
ECHOSURG	38	0,63	1	0	2	0	1	1	0,67
EKGPOST	38	2,08	2	0	9	1	3	2	1,84
EKGPRE	38	3,18	2,5	0	9	1	4,5	3,5	2,51
EKGSURG	38	0,37	0	0	11	0	0	0	1,81
FYSIOPOS	38	11,16	9	0	38	6	13,5	7,5	7,90
FYSIOPRE	38	1,87	2	0	8	1	2	1	1,58
FYSIOSUR	38	2,42	2	1	14	1	2	1	2,24
RXPOST	38	4,45	4	0	23	3	4	1	3,72
RXPRE	38	2,92	2	0	11	1	4	3	2,22
RXSURG	38	2,95	2	0	20	1	3	2	3,40
CATHPOST	38	0,00	0	0	0	0	0	0	0,00
CATHPRE	38	0,97	1	0	1	1	1	0	0,16
CATHSURG	38	0,03	0	0	1	0	0	0	0,16

Table The bill of resources for DRG 105

BILL OF RESOURCES FOR DRG 105									
CASENAN	N	MEAN	MEDIAN	MIN	MAX	LOWQUA	UPQUA	QUARTILE	STD_DEV_
LOSPOST	87	212,87	195	0	502	171	243	72	69,98
LOSPRE	87	66,89	48	5	739	45	54	9	87,18
LOSSURG	87	55,36	47	13	460	27	67	40	53,20
ECHOPOS	86	1,08	1	0	2	1	1	0	0,35
ECHOPRE	86	1,17	1	0	2	1	2	1	0,60
ECHOSUR	86	0,52	0	0	2	0	1	1	0,59
EKGPOST	86	1,90	2	0	5	1	2	1	1,10
EKGPRE	86	0,86	1	0	3	1	1	0	0,56
EKGSURG	86	0,27	0	0	15	0	0	0	1,68
FYSIOPOS	86	7,62	7	0	16	6	9	3	2,74
FYSIOPRE	86	1,52	1	0	22	1	2	1	2,38
FYSIOSUR	86	2,01	2	0	16	1	2	1	1,86
RXPOST	86	3,87	3	0	12	3	4	1	1,75
RXPRE	86	1,12	1	0	8	1	1	0	0,83
RXSURG	86	2,47	2	0	21	1	3	2	2,47
CATHPOS	86	0,00	0	0	0	0	0	0	0,00
CATHPRE	86	0,00	0	0	0	0	0	0	0,00
CATHSUR	86	0,00	0	0	0	0	0	0	0,00

Table The bill of resources for DRG 106

BILL OF RESOURCES FOR DRG 106									
CASENAN	N	MEAN	MEDIAN	MIN	MAX	LOWQUA	UPQUA	QUARTILE	STD_DEV_
LOSPOST	112	244,24	192	0	1277	171	237,5	66,5	185,18
LOSPRE	112	142,38	119,5	0	663	51	190	139	121,73
LOSSURG	112	67,70	48	11	795	42,5	67	24,5	89,95
ECHOPOS	110	1,10	1	0	3	1	1	0	0,47
ECHOPRE	110	1,20	1	0	6	0	2	2	0,97
ECHOSUR	110	0,36	0	0	4	0	1	1	0,69
EKGPOST	110	1,90	2	0	10	1	2	1	1,51
EKGPRE	110	2,96	2	0	12	1	4	3	2,72
EKGSURG	110	0,59	0	0	25	0	0	0	2,91
FYSIOPOS	110	7,96	7	0	47	6	8	2	5,87
FYSIOPRE	110	1,67	1	0	10	0	2	2	1,84
FYSIOSUR	110	2,41	2	0	22	1	2	1	2,70
RXPOST	110	4,01	3	0	36	3	4	1	3,58
RXPRE	110	2,07	2	0	10	1	3	2	1,69
RXSURG	110	3,15	2	0	36	2	3	1	4,43
CATHPOS	112	0,03	0	0	2	0	0	0	0,21
CATHPRE	112	0,90	1	0	2	1	1	0	0,33
CATHSUR	112	0,09	0	0	2	0	0	0	0,32

Table The bill of resources for DRG 107

BILL OF RESOURCES FOR DRG 107									
CASENAME	N	MEAN	MEDIAN	MIN	MAX	LOWQUA	UPQUA	QUARTILE	STD_DEV_
LOSPOST	127	226,43	192	0	1109	171	217	46	146,09
LOSPRE	127	56,04	48	0	270	45	54	9	31,65
LOSSURG	127	53,18	47	12	262	36	66	30	36,15
ECHOPOST	123	1,08	1	0	4	1	1	0	0,42
ECHOPRE	123	1,14	1	0	3	1	1	0	0,52
ECHOSURG	123	0,24	0	0	2	0	0	0	0,45
EKGPOST	123	1,92	2	0	16	1	2	1	1,62
EKGPRE	123	0,89	1	0	4	1	1	0	0,62
EKGSURG	123	0,16	0	0	5	0	0	0	0,77
FYSIOPOS	123	7,67	7	0	33	6	8	2	4,40
FYSIOPRE	123	1,34	1	0	4	1	2	1	0,71
FYSIOSUR	123	2,03	2	0	11	1	2	1	1,48
RXPOST	123	3,60	3	0	16	3	4	1	1,63
RXPRE	123	1,03	1	0	5	1	1	0	0,53
RXSURG	123	2,36	2	1	14	2	3	1	1,79
CATHPOST	125	0,00	0	0	0	0	0	0	0,00
CATHPRE	125	0,02	0	0	1	0	0	0	0,15
CATHSURG	125	0,00	0	0	0	0	0	0	0,00

APPENDIX 8

THE SIMULATION PROGRAM AND DOCUMENTATION

APPENDIX 8 SIMULATION OF A CARDIAC SURGERY UNIT AND HSRP

This appendix has two parts. In the first part we document the simulation program which is listed in the second part.

The simulation program has been written by PAUL GEMMEL.

The simulation program contains some features which allow to expand the research as described in the thesis. For instance, there is the possibility to introduce more DRG patient groups.

1. DISCUSSION OF THE SIMULATION PROGRAM

A simscript II.5 program consists of three primary elements (Russell, 1992):

1. A preamble giving a static description of each modelling element;

2. A main program where execution begins;

3. A process routine for each process declared in the preamble.

Besides these more dedicated elements, a SIMSCRIPT II.5 program also contains other routines or subprograms.

1.1.Preamble

This module is purely declarative. It includes no executable statements. All the modelling elements (processes and resources) are named in this module. The module has several sections: global variables, temporary entities, permanent entities, random step and linear variables, processes, time-scaling, functions and routines, statistics collection and graphics.

1.1.1. Global variables

A global variable is a variable whose name has a common meaning throughout a program. These variables must be defined in the preamble. They are different from the local variables which have a value defined only within a particular routine.

Table 1 lists the global variables. They are listed in alphabetic order. The following variables are input parameters and are listed in table 5: RUN.LENGTH, WARMUP.PERIOD, RESET.INTERVAL, RESET.TIME, P5, P6, SEED1...SEED10, SI.RX3, SI.RX4,

PLANNING.PERIODICITY, P1, P2, P3, P4, PLANNING.HORIZON, START.STAT, ICU.BEDS and DESIGN.

Table 1 Definition of global variables:

VARIABLE	DEFINITION
ACTUAL.RX.DAY	This variable is used to represent the actual number of daily chest X-rays in a graphical output
AVGLOS.PRE.104, AVGLOS.PRE.105, AVGLOS.PRE.106, AVGLOS.PRE.107, AVGLOS.SURG.104, AVGLOS.SURG.105, AVGLOS.SURG.106, AVGLOS.SURG.107, AVGLOS.POST,104, AVGLOS.POST.105, AVGLOS.POST.106, AVGLOS.POST.107, AVGLOS.TOTAL.104, AVGLOS.TOTAL.105, AVGLOS.TOTAL.106, AVGLOS,TOTAL.107	The average length of stay for patients belonging to a certain DRG category and in a certain stage or for the total stay. This parameter contains the standards used in the HSRP system
AVG.NO.BEDS.8140	This variable allows to produce graphical output of the daily bed utilisation of department 8140C. It is equal to NO.BEDS.8140
AVG.RX.PRE, AVG.RX.POST, AVG.RX.SURG	The average daily number of Rx actually consumed in the different stages
BLOCK.TEL	The number of patients which are registered as being blocked
BLOCKTIME	The proportion of preoperative time that patients are blocked
COUNT	Counter of the total number of patients generated (used for patient identification)
CURRENT.LATENESS	The difference between the most recently updated scheduled discharge date and the actual discharge date
DAY.COUNTER	A counter of the number of days which have passed.
DISCHARGE.NUMBER	The total number of discharges
DRG.HISTO	Variable used in defining a histogram of the case-mix.
HELP.1PGE, HELP.2PGE	Help variables to transfer data between files.
LATENESS.TIME	The difference between the original scheduled discharge date and the actual discharge date

MPS.NUMBER; MPS1.NUMBER	The total number of discharges for DRG 107 patients and DRG 104 patients on a particular day.
NO.BEDS..8140	The daily bed utilisation of department 8140C
NO.BEDS.ICU	This variable allows to track the occupancy of department 8327 in a graphical way
NUMBER.OF.ADMISSIONS	The number of admissions generated by a Poisson distribution each 24 hours.
NUMBER.OF.DISCHARGES	The total number of discharges (gross requirements) on a particular day (independent from DRG)
NUMBER1.OF.DISCHARGES	The total number of discharges on a particular day for DRG 104 patients
MPDBED.FOR.DAY; MPDRX.FOR.DAY	The daily MPDBED and MPDRX performance measures
OCC.DPT8140; OCC.DPT8327	The daily bed utilisation of department 8140C and 8327C
PLAN.RX.DAY	The scheduled number of daily chest X-rays as defined in a graphical output report.
PRE.LENGTH, POST.LENGTH, SURG.LENGTH	The preoperative, postoperative and surgical length of stay of a particular patient
PRE.LOS.104, PRE.LOS.105, PRE.LOS.106, SURG.LOS.104, SURG.LOS.105, SURG.LOS.106, SURG,LOS.107, POST.LOS.104, POST.LOS.105, POST.LOS.106, POST.LOS.107, TOTAL.LOS.104, TOTAL.LOS.105, TOTAL.LOS.106, TOTAL.LOS.107	Pre-operative, post-operative, surgical and total length.of.stay for each patient of respectively DRG104, DRG105, DRG106 and DRG107. It is used to calculate the average length of stay for each category and for each stage.
PRE.RX	Total number of RX consumed by patients in the preoperative stage (after warmup.period and until reset.time). PRE.RX is used to calculate an average number of preoperative RX per patient and is used as a standard in the HSRP calculations.

POST.RX	Total number of RX consumed by patients in the postoperative stage (after warmup.period and until reset.time). POST.RX is used to calculate an average number of postoperative RX per patient and is used as a standard in the HSRP calculations.
RX	The number of chest X-rays assigned to a particular patient in a particular stage
RX.NO.2; RX.NO.8, RX.NO.83, RX.NO.85	The daily number of chest X-rays consumed in department 2191d, 8140C , 8327C and 8325D
SQUARE.CURLAT	The square of the current lateness
SURG.RX	Total number of RX consumed by patients in the surgical stage (after warmup.period and until reset.time). SURG.RX is used to calculate an average number of surgical RX per patient.
TIME.PARAMETER	= time.v, the time in the simulation
TOTAL.LOS.AVG	This variable is equal to AVG.LENGTH.OF.STAY. It is used for graphical output
TRANSFER	The number of transfers to the ICU unit (DPT.8327C).

1.1.2. Temporary entities

A temporary entity is used to model an object or data-item which is short-lived in the model or for which the number of copies varies within the execution of the model. Temporary entities may have attributes and either belong to or own sets. There are two temporary entities: PATIENT and DAY. The PATIENT is the patient who flows through the hospital and who is planned in the HSRP system. The DAY is a day time bucket in the HSRP system.

A patient has the following attributes:

Table 2 The attributes of the temporary entity PATIENT

ATTRIBUTE	Definition
ARRIVAL.TIME	The arrival time of the patient in each stage of his/her stay
BLOCK.TIME	The time when a patient enters the arrival queue before department 8327 where capacity can be limited
DEPARTURE	The department where the patient is admitted.
DISCHARGE.TIME	The original discharge date of the patient on the MPS
DISCHARGE.TIME.RE	The current discharge date of the patient on the MPS
DRG	This is the DRG category to which the patient belongs
EMERG	This 0/1 variable is 1 for an emergency admission.
LOS	This attribute shows the time on which a patient is discharged from a particular department during his/her flow.
MPS.CHANGE	This holds the value of the difference (in number of days) between the current discharge date (on the MPS) and the new discharge date which takes into account the actual finish date of the preoperative stage.
OK.TEST	When the patient has got surgery this variable is changed from 0 to 1. It is important for patients who have more than 1 surgery during the same stay, but on different time periods.
PATH	This 0/1 variable is 1 when 2191 (cardiology) is the admitting department
PATIENT.ID	A unique identification number of the patient
PLAN.ADMISSION/PLAN.ADMIT	The planned admission date of the patient (for emergencies, this attribute is equal to the current time)
POST.LOS	The postoperative length of stay of a particular patient
PRE.LOS	The pre-operative length of stay of a particular patient

RXS	The total number of Chest X-rays for a patient during his/her stay in a particular department during a particular stage.
SCHEDULE.TIME	The length of stay of a patient on a particular department during his/her flow
SURG.LOS	The surgical length of stay of a particular patient
TIME.INT	The time-interval between two succeeding consumptions of Chest X-ray in a particular department
TOTAL.RX	This variable registers the total number of RX a patient has received for each stage of his/her stay.

Entities belong to sets. A set is an organised collection of entities. Sets are like arrays in that each of the entity elements of which they are composed may be identified and manipulated, but in contrast with the static structuring imposed on array elements, the organisation of entities in sets may be dynamic and changeable. Each PATIENT may belong to the following sets:

+ the ARRIVAL.QUEUE is a set of patients which must be admitted in a specific department.
+ the DONE.QUEUE is a set of patients which are going to leave the hospital
+ the LIST.OF.PATIENTS is a set where all patients which are in the hospital are residing.

In SIMSCRIPT II.5 each set must be owned. The three sets are owned by the system.

The second entity DAY has the following attributes:

Table 3 Attributes of the entity DAY

ATTRIBUTE	Definition
ACTUAL.RX.FOR.DAY	The total number of daily chest X-rays consumed on all departmens
ACTUAL.BED.FOR.DAY	The total number of daily beds utilised on all departments
DAY.NUMBER	The day number (unique identification)
NO.OF.DISCHARGES	The gross requirements (scheduled number of discharges) on a particular day in MPS DRG 107 in the current explosion
NO1.OF.DISCHARGES	The gross requirements (scheduled number of discharges) on a particular day in MPS DRG 104

NO.FOR.OR	The number of cases scheduled for surgery on a particular day
NO.POST.OPERATIVE	The number of DRG 107 patients scheduled to be in the post-operative stage on a particular day.
NO1.POST.OPERATIVE	The number of DRG 104 patients scheduled to be in the post-operative stage on a particular day.
NO.PRE.OPERATIVE	The number of DRG 107 patients scheduled to be in the pre-operative stage on a particular day.
NO1.PRE.OPERATIVE	The number of DRG 104 patients scheduled to be in the pre-operative stage on a particular day.
NO.SURGICAL	The number of DRG 107 patients scheduled to be in the surgical stage on a particular day.
NO1.SURGICAL	The number of DRG 104 patients scheduled to be in the surgical stage on a particular day.
PLAN.BED FOR.DAY	The total number of DRG 107 patients scheduled in any stage in the hospital on a particular day
PLAN1.BED.FOR.DAY	The total number of DRG 104 patients scheduled in any stage in the hospital on a particular day
PLAN.RX.FOR.DAY	The total number of chest X-rays scheduled to be consumed by all DRG 107 patients on a particular day
PLAN1.RX.FOR.DAY	The total number of chest X-rays scheduled to be consumed by all DRG 104 patients on a particular day
PRE.NO.OF.DISCHARGES	The gross requirements (scheduled number of discharges) on a particular day in MPS DRG 107 in the previous explosion
PRE1.NO.OF.DISCHARGES	The gross requirements (scheduled number of discharges) on a particular day in MPS DRG 104 in the previous explosion

There are two sets of days: the MPS.DRG104 and MPS.DRG107. (The other sets are not activated). These sets are ranked from low to high daynumber. This assures that after the removal of a day from the set for some calculation, the day is put back on the right place in the set. The system owns these sets.

1.1.3. Permanent entities

Entities declared as permanent are stored collectively rather than in individually identifiable records. The attributes of the entities in the group are stored as indexed arrays; the attributes for a particular entity are accessed by selecting a common index for all the associated attribute arrays. Permanent entities are not dynamic.

Resources are implemented as an extension of permanent entities. We model the different departments as resources. They have a unique identification number (DPT.ID) and they own a department.queue. This is not a real queue if the capacity of the department is not limited. The department.queue is a mechanism to transfer patients from one department to another. Each department belongs to the set LIST.OF.DEPARTMENT.

1.1.4. Random step variables and random linear variables

In this section the variables which are used to make random sampling out of empirical distributions are defined. The MTR.***** allows to sample in a random way from a distribution which shows the probabilities that a patient who stays on a certain department or stage, goes in the next state to other departments or stages. For instance MTR.2192D samples out of the cumulative distribution in table 4.This is the first row out of the transition probability matrix in table 4.4 in the text.

Table 4 The MTR.2192D random step variable for patients staying on 2191D preoperative.

CUMULATIVE PROBABILITY	DESTINATION
0.69	8140C
0.935	8325D
1.00	8327C

For the underlying length of stay distributions, random linear (step) variables are defined. The difference between step and linear variables is that in the latter case interpolation is performed between categories.

The same kind of variables are defined for sampling the number of chest X-ray when the patient remains on a certain department (RX.NO.DPT1 is applied for department 2191D, preoperative; RX.NO.DPT2.PRE for 8140C, preoperative and RX.NO.DPT2.POST for

8140C, postoperative). Remark that these are the departments where the consumption of chest X-rays is not length of stay dependent.

A random step variable is defined for determining whether a demand for admission has an emergercy nature or not and whether the patient is misclassified or not. A different random number stream is assigned to each different variable.

1.1.5. Processes

A process represents an object and the sequence of actions it experiences throughout its life in the model. When a process is activated, the description of its activity is contained in a process routine. The different process routines are described in following sections.

1.1.6. All times scaled in hours

Definition of the time-scale used throughout the simulation. Every progress in time is stated in hours.

1.1.7. Functions and routines

Definition of a special function needed in the trace.files.

1.1.8. Statistics collection

In this section, the different statistics which are collected during the simulation are described. Two features, accumulate and tally allow such information to be gathered during a simulation run, without requiring any other explicit action to be specified within the program. "Tally DEV.UTILIZATION.DEPARTMENT as the std.dev. of OCC.DPT8140" means that the standard deviation of the occupancy of department 8140 must be gathered. Accumulate calculations introduce the simulation time into the average and the standard deviation, weighting the collected observations by the apparent length of simulation time for which these values have held. Based on the definition of each variable (see table 1), one can easily understand the different data collection commands. We only remark that N.X.DEPARTMENT is a system-defined attribute of the resource department. It holds the utilisation of the department at each moment of the simulation.

1.1.9. Graphics

This section allows to display some variables in a graphical way. For instance "display variables include PLAN.RX.DAY" means that the scheduled number of daily chest X-rays are graphically displayed.

1.2. Main.

This module is the heart of the model. It calls the initialization module. activates the modules which generate the MPS and the resources such as departments. It also calls the planning time process and the reset.statistics. A simulation begins when control passes to a system-supplied timing routine. This is done by executing the START SIMULATION statement. Any statements following the START SIMULATION statement will not be executed until the simulation has terminated. If the simulation has finished, the output units are closed. [18]
The "display" commands in the beginning of this module allow to introduce some graphical output.

1.3. Initialise

In the initialisation routine, the input parameters are read. First, the parameters for DATA.DAT are read (lines 8-117). Table 5 shows the different input parameters and their meaning.

Table 5 Input parameters

INPUT PARAMETER	DEFINITION
RUN.LENTH	Total run length inclusive warm-up period (number of days)
WARMUP.PERIOD	Warm-up period of the shop level
RESET.INTERVAL	The length of each subrun (the size of each batch) in the simulation of one treatment
RESET.TIME	Interval during which statistics are colleced in function of making standards
START.STAT	Warm-up period of the HSRP system
PLANNING.HORIZON	The planning horizon used for MRP explosion.
NUMBER.OF.DEPARTMENTS	The number of clinical departments in the system
SI.RX3, SI.RX4	The average daily chest X-ray resource use (in terms of number per day) for department 8325 and department 8327
MTR.START, MTR.2191D, MTR.8140C, MTR.8325D, MTR.8327C, MTR2191DO, MTR.8140CO, MTR.8325DO, MTR.8327C2, MTR.8140CO2, MTR.8327C2, MTR.8140CO3	Through these variables, the transition probability matrix is read into the model. Each of the variables shows the % chance that a patient staying in a certain state is going to a next state.(transition probability)

[18] Output units are an address where the output reports are stored.

LOS5, LOS6, LOS7, LOS9, LOS10, LOS11, LOS12, LOS13, LOS15, LOS16, LOS17, LOS21, LOS23, LOS24, LOS28, LOS29, LOS30, LOS31, LOS35, LOS36, LOS37, LOS38, LOS42, LOS44, LOS49, LOS50, LOS60, LOS62, LOS67	The empirical length of stay distributions related to each (non-zero) cell in the transition probability matrix
RX.NO.DPT1	The empirical discrete distribution of the number of RX consumed through a patient during his/her stay on department 2191
RX.NO. DPT2.PRE, RX.NO.DPT2.POST	The empirical discrete distribution of the number of RX consumed through a patient during his/her preoperative and postoperative stay on department 8140

In "EXPERIMENT.DAT", the levels for the experimental factors are read (lines 119-140). PLANNING.PERIODICITY, EMERGENCY, CASE-MIX ERROR are evident. In the following table, we further define the other factors.

Table 6 Parameters and their meaning

PARAMETER	DEFINITION
P1	Dynamic order due date maintenance
P2	Capacity limits
P3	Admission scheduling
P5	Lead-time uncertainty
P6	Safety lead-time

NUMBER.FOR.OR is used to limit the number of OR beds available (if applicable). DESIGN is a parameter used to select the right treatment during simulation. In SEED.DAT (lines 142-163), the seeds of the random number streams are read and defined (lines 165-174).

In this routine, the units (adresses) of the output reports are opened (lines 180-240). There are three important output reports:RESULTAAT.DAT, OPERATING.RESULTS and MPS.RESULT. There are 3 trace files :TRACE.DAT, TRACE.DAY, TRACE.MPS.[19]

[19] The other output reports are more used for special purposes such as tracking of the occupancy of a department over time.

1.4. Process Planning.Time

It is an event driven timing module. The event is 24 hours which pass (line 31). Each 24 hours, a number of demands for admission are generated according to a Poisson distribution with lambda 1.3 (stream 8)(line 14). The further specification of the patients is performed in another module 'GENERATE.PATIENTS' (lines 16-18). This module PLANNING TIME activates the module ANCILLARY.SERVICE calculating the daily planned and actual resource requirements (line 19). This module also calls the MPS.DRG.104 routine which is the first routine in the MRP explosion process. This occurs every 'PLANNING.PERIODICITY' days (lines 24-29). In order to know whether PLANNING.PERIODICITY days are passed, a .DAYCOUNTER is updated each time the loop is repeated (line 22) and the loop is repeated until RUN.LENGTH is reached (line 12). Some other daycounters are also introduced (lines 20-21).

The TOTAL.LOS.AVG calculation in line 23 allows to display the variable AVG.LENGTH.OF.STAY with a dynamic graphical figure. The NO.BEDS.ICU allows to track the ICU occupancy in a graphical way (line 30).

1.5. Process Ancillary.Service

One of the functions of this process is to track the daily occupancy of the different departments in order to calculate the daily consumption of resources which are length of stay dependent (lines 9-42). In the following table, we show the different departments and their number as used in the simulation model.

Table 7 The departments and their number in the simulation model.

DEPARTMENT	NUMBER
Department 2191D	1
Department 8140C	2
Department 8325D	3
Department 8327C	4

In lines 40-72, daily statistics are collected on the actual and planned resource consumption (for beds and chest X-rays) across the different MPS schedules. The ACTUAL.RX.FOR.DAY (line 51) is the sum of the daily Chest X-ray consumption in the departments 2191 and 8140 (kept by the global variables RX.NO.2 and RX.NO.8) and the daily chest X-ray consumption in departments 8325 and 8327 collected in lines 31 and 39. The ACTUAL.BED.FOR.DAY (line 52) is the sum of the daily occupied beds in the different departments (statistics collected in lines 13, 23, 32 and 40). In lines 45-75, the MPDRX and MPDBED performance measures are collected. The actual resource utilisation (calculated in lines 51-52) is compared with the planned resource utilisation (calculated in the MPS.DRG104 and MPS.DRG107 modules). This only occurs after the system has totally warmed up.

1.6. Process Generate.Patients

In this module, patients are further specified. Different attributes such as patient identication and the department where the patient will be admitted are assigned (lines 17-20). In lines 22-32, based on a random step input parameter EMERGENCY, it is determined whether a patient is an emergency or not. In the case of emergency, a patient will be immediately admitted. In the case of non-emergency, the admission date is scheduled using a lognormal-distribution.
If the patient starts at the 2191 department (cardiology), he/she receives a flag 1 (path attribute)(lines 34-35). Patients with a path = 1 attribute belong to DRG 104. The other patients are DRG 107 patients (lines 38-44).
Another random step input parameter CASE-MIX ERROR determines the level of error in classifying patients. For instance when it is specified that 1 on 2 patients are wrongly classified, one on two times the previously assigned DRG number is changed (lines 46-58) for planning purposes.
Next all patients (emergencies included) are filed into two sets of patients (lines 62-63). The processes FLOW OF PATIENT THROUGH DPT and MASTER.SCHEDULE are activated (lines 64-65). The former process starts the actual flow of patients through the hospital departments dependent on the admission date. The latter process schedules the discharge date of patients into the DRG specific MPS.

1.7. Process Master.Schedule

In this process, generated patients are scheduled in the DRG specific MPS. Patients are first removed from the different sets (lines 7, 8). Dependent on the number of the DRG category, a MPS is chosen. For instance for DRG 104 (lines 11-26), based on the planned admission date and the standard average length of stay of DRG 104 patients, the discharge date is calculated. This day is then removed from the MPS for DRG 104 patients and the gross requirements (NO1.OF.DISCHARGES) on this day is increased with one. Some attributes are created to keep track of the original and the current discharge dates on the MPS (lines 18-19). The same procedure is repeated for DRG 107 patients (lines 52-67). The cases 105 and 106 are not used (lines 28-50).

1.8. Process Flow.Of.Patient.Through.Dpt

In this process, patients are admitted on the right admission date and sent to the appropriate admission department. Each day, the process is activated and all patients in the set

ARRIVAL.QUEUE are serviced. In lines 10-15, patients are kept waiting until their admission date. This reflects the time between patient demand and actual admission based on the planned admission date.

Once the current date is the admission date, patient is admitted and this admission time is kept in an attribute (line 19). In lines 21-59 a procedure is developed to find the admitting department which has been assigned to each patient during creation (see process GENERATE.PATIENTS). Patients are placed in a queue before this department. This is not a real queue, but it is a set which is necessary to create a link between this module and the different department modules. The process on the identified admitting department is then activated.

The flow of patients through the different departments is completely based on a transition probability matrix. Using linear random variables patients in a certain department receive a destination (department or leaving the hospital). This destination is not influenced by the previous sequence of departments the patient has visisted. The length of stay in the current department depends on the nature of the current department and of the destination.

1.9. Process DPT.2192

This process models the 2191 or the cardiology department.

The primary function of this process is to assign a length of stay to each patient taking into account the current department and the destination, and based on some kind of length of stay distribution. The attribute DEPARTURE always shows the origin of the patient. For instance DEPARTURE = 1 means that the patient is just admitted (lines 24-25), while DEPARTURE = 5 means that the patient comes from the intensive care unit (line 146). The attribute ARRIVAL always shows the destination of the patient. As soon as a patient arrives in a certain department, a destination is assigned through a random step variable (e.g. lines 27-28; 147-148) For instance ARRIVAL = 2 means that the 8140 department (line 29) is the destination while ARRIVAL = 3 means that the 8325 department (line 71) is the destination. The destination becomes the departure for the next department (e.g. line 29).

This destination determines the length of stay distribution which will be used for the particular patient in this department. An empirical distribution (lines 37, 73, ...) or a theoretical (normal) distribution (lines 32) is used to describe the length of stay. This normal distribution has a parameterized standard deviation ('*p5', line 32). This allows to change the lead-time uncertainty. Only the high-volume matrix cells have been modelled with a theoretical distribution.

The secondary function of this process module is to register the actual resource consumption for these resources which are not length of stay dependent (e.g. chest X-ray in this department).
Using a random step variable, the actual amount of resources consumed by a particular patient is assigned (lines 20-22). Statistics are collected which allow to calculate average resource consumption in the preoperative and postoperative stage (line 23).

The procedure in lines 43-58 models the length of stay of a patient on this department. For patients with a non-zero number of chest X-rays, the length-of-stay of the patient is divided into time-intervals (lines 44, 50-55). After each time-interval, a chest X-ray is performed and registered (line 52). As long as the patient has not achieved his/her discharge date on this department (line 49), a new time interval and thus chest X-ray consumption is added (lines 50-55). This spread of resource consumption over the length-of-stay is important when daily statistics are consumed. In other words it is assumed that the total number of chest X-rays for a patient is not consumed on one day, but during his/her length-of-stay in this department. It is further assumed that this occurs with fixed time-intervals. Patients with no chest X-ray have only one time-interval (line 57). The same procedure can be found in the other cases (e.g. lines 78-93)

When the stay of the patient on this department is finished, the patient leaves this department and is put in the queue of the destination department or in the patient done queue. The process related with this destination department or with the patient.done queue is then activated (lines 62-69). For patients with the intensive care unit (8327C) as destination (for instance case DEPARTURE(.PATIENT) = 4 on lines 106-143), a BLOCK.TIME attribute is introduced to keep track of the arrival time in the queue before this department (line 132).

For each 'CASE' and for each ARRIVAL(.PATIENT), the previous described procedure is repeated.

1.10. Process DPT.8325

This process models the 8325 department, i.e the general intensive care unit. The general layout of this process is strongly analoguous with the description of the process DPT.2192.
The only difference is that in this department the actual consumption of chest X-rays is modelled in another way because in this case, the consumption is length of stay dependent. The

number of chest X-rays is determined using a constant input parameter describing the number of chest X-rays per 24 hours (e.g. line 26 and line 52).

1.11. Process DPT.8140

This process models the 8140 department, i.e the medical care unit of the heart surgery department. The general layout of this process is strongly analogous with the description of the process DPT.2192. There are more cases in this process.

1.12. Process DPT.8327

This process models the 8327 department, i.e the intensive care unit of the heart surgery department. The general structure is the same as the previously described processes, but there are some additional features built in. Because this is also an intensive care unit, the chest X-ray consumption is modelled as in the process DPT.8325.

This intensive care unit can be modelled with finite capacity. This means that the DEPARTMENT.QUEUE before this department is a real queue where patients have to wait because of capacity limits (see lines 16-22). Two statistics are collected: the number of blockings (line 19) and the average blocked time as compared with the preoperative length of stay (line 20).

In lines 28-29, some length of stay statistics of the preoperative length of stay are collected.

Lines 27-48 show a feature to create a link between the actual flow of the patients and the MPS. If the patient belongs to the DRG 107 category (lines 32-35), it is calculated how many days earlier or later than scheduled the patient arrives at the intensive care unit. This is based on a comparison of the actual preoperative length of stay (calculated in line 28) and the planned (or average) preoperative length of stay (kept in the statistic AVGLOS.PRE.107). The difference in days is hold in an attribute 'MPS.CHANGE'. The same procedure is available for DRG 104 patients (lines 36-39). If the MPS.CHANGE attribute is not zero, a process called 'CHANGE.MPS' is activated in order to change the discharge date in the MPS (lines 42-46). .

In lines 66-81, a dinstinction is made between patients who are in the ICU for the first time (first surgery)(lines 67-73) and patients who have already been in the ICU (second or third surgery)(lines 75-80). The first surgery is considered as the primary surgery. Statistics are kept as statistics of the surgical stage. When patients enter a second or third time this department, they are in their postoperative stage. The statistics are characterized as postoperative. Remark that the TIME.INT attribute on line 75 has another meaning than in the table. In this case, it is used as a help variable which is equal to the average number of chest X-rays per day on the intensive care unit (SI.RX4).

In lines 88 (e.g.) a new arrival.time is set to indicate the start of the postoperative stage.

1.13. Routine Patient.Done

In this routine, the finished patients are discharged from the hospital and statistics are collected. In lines 17-20, statistics are collected independent from the DRG category to which the patient belongs.

In lines 23-72, statistics are collected for each DRG category. For instance for DRG 104, this concerns statistics about the length of stay (lines 24-27) or about the lateness of the orders (lines 29-45) in function of the calculation of MADCUR and MADHIST. For DRG 107 (lines 52-75) the same procedure is applied.

In line 77 the patient who leaves the hospital is destroyed , i.e. removed from the system.

1.14. Process Generate.MPS

In this process, the MPS is developed for the total length of the simulation (days). At the start a MPS horizon is created which is equal to the RUN.LENGTH and one time the RESET.INTERVAL (lines 12).Each day has a unique identification number (line 16). Two sets of days are made up (lines 17-18).

1.15. Process Generate.Departments

In this module, a number of departments are created as resources. This gives the model some flexibility to expand the number of departments. This model has been written for four departments. The number of beds for each department is set in such a way that the system has infinite bed capacity in all the departments.

In the case of finite capacity, the capacity of the ICU bed resources is set equal to ICU.BEDS which is an input parameter (lines 15-19).

1.16. Process Reset.Statistics

After the warmup-period and after each reset interval, an output report 'write.result' is called (lines 8, 40).

After RESET.TIME some variables take on the current value of some statistics (lines 10-30). Remark the introduction of the 'P6' parameter in these formulas. This parameter allows to introduce a safety lead-time. These parameters are the standardised figure (length of stay, resource use) which will be used in the development of the MPS in the following periods.

Lines 44- 55 help to track the seeds of the random number streams used in each simulation run. Lines 59-369 are necessary to make an automatic succession of the different treatments possible. Because each treatment requires other parameter values, the whole simulation model must be started up again each time another treatment must be simulated. It is possible to do this startup automatically using DOS commands in the simlab environment. The procedure in lines 59-369 assures that each time a new treatment is started, the right parameters are used. In the example only treatments 66-128 are modelled [20]. Each time, the parameters of the current treatment are saved in an output file on unit 42 (lines 374-388). This output file is an input file for the next treatment (case).

1.17. Routine MPS.DRG.107

This routine contains the MRP explosion (for DRG 107 patients).
Lines 12-27: the current days (.DAYS1) is determined and using the planning horizon parameter, it is determined what the last day is for the current offsetting (.FDAYS1).
lines 29: for each day of the planning horizon, the changes in the number of patients to be discharged on this day are calculated in .MPS.NUMBER. If this number is zero, no explosion occurs for this particular day (net change method). .
Lines 40-82: For each day between the current day (.DAYS1) and the last day (.FDAYS1) in the offsetting process (line 29) - we call this day offsetting day -, it is calculated how far backwards scheduling must be performed. In general, backwards scheduling can stop when the current date has been reached. This means that when the date of the offsetting day is smaller than the current date enhanced with the total lead-time, the current date becomes the last day in the offsetting process (lines 50-57; 72-79). If this is not the case, offsetting is performed until the last day is reached. Some other procedures are built in to avoid that unnecessary offsetting is performed (e.g. lines 41-44). When the last day in the offsetting process is smaller than the current day minus the planning.periodicity, it is not meaningful to further offset the discharges on this day because the lead-time is a fixed value (lines 43-44) and no new patients can be scheduled on the dates between the date of the last MRP explosion and the date determined by the sum of the last MRP-explosion and the lead-time. This is not true when there is dynamic

[20] We have run the simulation on two PCs. The program loaded on the other PC contains the cases 1 to 65.

order due date maintenance (see the if then else structure on line 40, 62, 84). When there is dynamic order due date maintenance, patients who have not reached their surgical stage on the last MRP explosion can still be rescheduled. This must be taken into account (lines 65-67).

Lines 88-137: for each offsetting day of the planning horizon and based on the .MPS.NUMBER on each day, offsetting is performed. Offsetting means that starting from the discharge date, the patient is assigned to a number of days postoperative care (lines 99-105). This number is based on statistics collected in the reset time run (AVGLOS.POST.107). Once it is known when the patient must arrive in the postoperative stage, the same procedure can be followed for the surgical stage (lines 107-114) and the preoperative stage (lines 115-122). These calculations change the day attributes NO.POST.OPERATIVE, NO.SURGICAL and NO.PRE.OPERATIVE. The PRE.NO.OF.DISCHARGES are also adapted in order to be sure that only net changes are taken into account (e.g. line 95).

In lines 127-131 some data for determining resource requirements are collected. The total numbers of patients in preoperative, postoperative and the surgical stage on the day of the current planning period are used to calculate the average planned resource consumption.

Finally, the routine WRITE.MPS.RESULT is called in order to generate output reports.

1.18. Routine MPS.DRG.104

This routine is totally analoguous to the routine MPS.DRG.107 but for another enditem (and thus MPS).

This routine comes first and calls the MPS.DRG.107 routine.

1.19. Routine Change.MPS

This routine changes the discharge (due date) of a patient in the MPS based on information which is collected on the shop floor (just after the preoperative stage and just before entering the intensive care unit dpt.8327). Dependent on the kind of DRG, the current discharge date (DISCHARGE.TIME.RE) of the patient in the MPS is sought (lines 15-26 for a patient of DRG 107; lines 40-51 for a patient of DRG 104). If this date is found, the number of discharges on this date is subtracted with one. In the following step, the new discharge date is put on the MPS (lines 27-38 for a patient of DRG 107; lines 52-63 for a patient of DRG 104). The attribute MPS.CHANGE retains the value of the number of days with which the discharge date of the patient has changed. When the new discharge date has been found, the number of discharges on this date is increased with one.

1.20. Routine Write.Result

This routine generates standard output reports on the average and the standard deviation of the length of stay (total, per DRG, per stage)(lines 4-50). The mean occupancy of each department is shown (lines 53-62) and the different performance measures are displayed (lines 67-97). The values of the different parameters are reset in function of a new data collection in the following iteration (lines 110-130). Table 4.8 in the text shows an example of this output report

1.21. Routine Write.MPS.Result

This routine allows to generate a report of the different MPS schedules for DRG 104 and 107 for each replanning period and for a length equal to the planning horizon. The daily actual and planned resource consumption statistics are also displayed. Table 4.11 in the text shows an example of this kind of output report.

1.22. Routine Operating.Room.Dat

This routine is designated to generate an output report with different frequency distributions: a frequency distribution about the number of admissions per day (lines 21-38), about the classification of patients in the DRG categories (lines 42-51) and about the number of discharges scheduled on the MPS each day during each MRP explosion (lines 53-68).

1.23. Routine Write.Trace.Line

This routine traces the temporary entity PATIENT during its flow through the hospital. It is introduced because of validation purposes. Table 4.9 in the text shows an example of this kind of tracefile.

1.24. Routine Write.Trace.Day

This routine allows to trace a patient as to his/her scheduling date in the MPS. This routine is a validation routine.Table 4.10 in the text shows an example of this kind of tracefile.

1.25. Routine Write.Trace.MPS

This routine allows to trace the number of patients scheduled (in a certain stage) at the moment of changes in this scheduling process. This is also a validation routine.

1.26. Funtion Rtot.F(.number)

This function is needed in the TRACE routines in order to transform the time.v variable in a text variable.

1.27. Routine Write.results.1 and Write.results.2

These routines are especially developed for getting data in the form necessary to perform ANOVA-analysis.

2. THE SIMULATION PROGRAM

Production and Technology Department
De Vlerick School voor Management
Universiteit Gent

Paul Gemmel

June 1995

```
''*********
Preamble
''*********

''Definition of global variables
''==============================

    Define PRE.LENGTH, POST.LENGTH, SURG.LENGTH,
    PRE.RX, POST.RX, SURG.RX, PRE.LOS.104, PRE.LOS.105,
    PRE.LOS.106, PRE.LOS.107, SURG.LOS.104, SURG.LOS.105,
    SURG.LOS.106, SURG.LOS.107, POST.LOS.104, POST.LOS.105,
    POST.LOS.106, POST.LOS.107, TOTAL.LOS.104, TOTAL.LOS.105,
    TOTAL.LOS.106, TOTAL.LOS.107, TOTAL.LOS.AVG, AVGLOS.PRE.104,
    AVGLOS.PRE.105, AVGLOS.PRE.106, AVGLOS.PRE.107, AVGLOS.SURG.104,
    AVGLOS.SURG.105, AVGLOS.SURG.106, AVGLOS.SURG.107, AVGLOS.POST.10
    AVGLOS.POST.105, AVGLOS.POST.106, AVGLOS.POST.107, AVGLOS.TOTAL.1
    AVGLOS.TOTAL.105, AVGLOS.TOTAL.106, AVGLOS.TOTAL.107,
    PLAN.RX.DAY, TIME.PARAMETER, AVG.RX.PRE, AVG.RX.POST, AVG.RX.SURG
    MPD.RX.FOR.DAY, MPD.BED.FOR.DAY, LATENESS.TIME, CURRENT.LATENESS,
    LT, BLOCK.TEL, BLOCKTIME, HELP.1PGE, HELP.2PGE, OCC.DPT8140,
    OCC.DPT8327, SQUARE.CURLAT, SI.RX3, SI.RX4 as real variables

    Define COUNT, NUMBER.OF.DEPARTMENTS, DAYCOUNTER, DAYSCOUNTER,
    NUMBER.OF.ADMISSIONS, DAY.COUNTER, DRG.HISTO,
    MPS.NUMBER, MPS1.NUMBER, NUMBER.OF.DISCHARGES, NUMBER1.OF.DISCHAR
    RX.NO.2, RX.NO.8, RX.NO.83, RX.NO.85, P1, P2, P3, P4, DISCHARGE.N
    NO.BEDS.8140, TRANSFER, DESIGN as integer variables

'' Definition of (some) input parameters
'' =====================================

Define RUN.LENGTH, WARMUP.PERIOD, RESET.INTERVAL, RESET.TIME, P5, P6,
    SEED1, SEED2, SEED3, SEED4, SEED5, SEED6, SEED7, SEED8, SEED9,
    SEED10, SI.RX3, SI.RX4 as real variables

Define PLANNING.PERIODICITY, PLANNING.HORIZON, START.STAT, ICU.BEDS,
    NUMBER.FOR.OR, P1, P2, P3 and DESIGN as integer variables


'' Definition of temporary entities
'' ================================

    Temporary entities
    Every PATIENT has    a PATIENT.ID,
                         an ARRIVAL.TIME,
                         a DISCHARGE.TIME,
                         a DISCHARGE.TIME.RE,
                         a DEPARTURE,
                         a LOS,
                         an EMERG,
                         an OK.TEST,
                         a PRE.LOS,
                         a POST.LOS,
                         a SURG.LOS,
                         a TOTAL.RX,
```

```
                          a PATH,
                          a DRG,
                          a PLAN.ADMISSION,
                          a PLAN.ADMIT,
                          a PLAN.PERIODICITY,
                          a SCHEDULE.TIME,
                          a BLOCK.TIME,
                          a TIME.INT,
                          a RXS,
                          a MPS.CHANGE,
                          and may belong to a ARRIVAL.QUEUE
                          and may belong to a DONE.QUEUE
                          and belongs to a LIST.OF.PATIENTS

     Define PATIENT.ID, DEPARTURE, OK.TEST, PATH, DRG, PLAN.ADMISSION,
     EMERG as integer variables

     Define ARRIVAL.TIME, TOTAL.RX, PRE.LOS, PLAN.ADMIT,
       POST.LOS, SURG.LOS, SCHEDULE.TIME, TIME.INT, DISCHARGE.TIME,
       DISCHARGE.TIME.RE, MPS.CHANGE, PLAN.PERIODICITY, BLOCK.TIME and
       as real variables

     The SYSTEM owns the ARRIVAL.QUEUE
     The SYSTEM owns the DONE.QUEUE
     The SYSTEM owns the LIST.OF.PATIENTS


     Every DAY has a DAY.NUMBER,
                    a NO.POST.OPERATIVE,
                    a NO1.POST.OPERATIVE,
                    a NO.SURGICAL,
                    a NO1.SURGICAL,
                    a NO.PRE.OPERATIVE,
                    a NO1.PRE.OPERATIVE,
                    a PRE.NO.OF.DISCHARGES,
                    a PRE1.NO.OF.DISCHARGES,
                    a PLAN.RX.FOR.DAY,
                    a PLAN1.RX.FOR.DAY,
                    a PLAN.BED.FOR.DAY,
                    a PLAN1.BED.FOR.DAY,
                    a ACTUAL.RX.FOR.DAY,
                    a ACTUAL.BED.FOR.DAY,
                    a NO1.OF.DISCHARGES
         and a NO.OF.DISCHARGES
         and may belong to a MPS.DRG104
''       and may belong to a MPS.DRG105
''       and may belong to a MPS.DRG106
         and may belong to a MPS.DRG107

     Define MPS.DRG104 as a set ranked by low DAY.NUMBER
''     Define MPS.DRG105 as a set ranked by low DAY.NUMBER
''     Define MPS.DRG106 as a set ranked by low DAY.NUMBER
     Define MPS.DRG107 as a set ranked by low DAY.NUMBER

     Define DAY.NUMBER, NO.POST.OPERATIVE, NO.PRE.OPERATIVE, NO.SURGIC
```

```
         NO1.POST.OPERATIVE, NO1.PRE.OPERATIVE, NO1.SURGICAL,
         PRE.NO.OF.DISCHARGES, PRE1.NO.OF.DISCHARGES, NO1.OF.DISCHARGES
         and NO.OF.DISCHARGES as integer variables

       Define PLAN.RX.FOR.DAY, ACTUAL.RX.FOR.DAY, ACTUAL.BED.FOR.DAY,
         PLAN1.RX.FOR.DAY, PLAN.BED.FOR.DAY, PLAN1.BED.FOR.DAY
         as real variables

       The SYSTEM owns the MPS.DRG104
 ''      The SYSTEM owns the MPS.DRG105
 ''      The SYSTEM owns the MPS.DRG106
       The SYSTEM owns the MPS.DRG107

''Definition of permanent entities
''================================

       Resources

       Every DEPARTMENT has a DPT.ID
                    and owns a DEPARTMENT.QUEUE
                    and belongs to a LIST.OF.DEPARTMENTS
       Define DPT.ID as an integer variable
       The SYSTEM owns the LIST.OF.DEPARTMENTS


''Definition of random step and random linear variables
''=====================================================

       The SYSTEM has a MTR.START random step variable
       The SYSTEM has a MTR.2191D random step variable
       The SYSTEM has a MTR.8140C random step variable
       The SYSTEM has a MTR.8325D random step variable
       The SYSTEM has a MTR.8327C random step variable
       The SYSTEM has a MTR.2191DO random step variable
       The SYSTEM has a MTR.8140CO random step variable
       The SYSTEM has a MTR.8325DO random step variable
       The SYSTEM has a MTR.8327C2 random step variable
       The SYSTEM has a MTR.8140CO2 random step variable
       The SYSTEM has a MTR.8327C3 random step variable
       The SYSTEM has a MTR.8140CO3 random step variable

       The SYSTEM has a LOS5 random linear variable
       The SYSTEM has a LOS6 random linear variable
       The SYSTEM has a LOS7 random linear variable
       The SYSTEM has a LOS9 random step variable
       The SYSTEM has a LOS10 random linear variable
       The SYSTEM has a LOS11 random linear variable
       The SYSTEM has a LOS12 random linear variable
       The SYSTEM has a LOS13 random linear variable
       The SYSTEM has a LOS15 random linear variable
       The SYSTEM has a LOS16 random linear variable
       The SYSTEM has a LOS17 random linear variable
       The SYSTEM has a LOS21 random step variable
       The SYSTEM has a LOS23 random step variable
       The SYSTEM has a LOS24 random step variable
```

```
     The SYSTEM has a LOS28 random step variable
     The SYSTEM has a LOS29 random linear variable
     The SYSTEM has a LOS30 random linear variable
     The SYSTEM has a LOS31 random linear variable
     The SYSTEM has a LOS35 random step variable
     The SYSTEM has a LOS36 random linear variable
     The SYSTEM has a LOS37 random linear variable
     The SYSTEM has a LOS38 random linear variable
     The SYSTEM has a LOS42 random linear variable
     The SYSTEM has a LOS44 random step variable
     The SYSTEM has a LOS49 random linear variable
     The SYSTEM has a LOS50 random linear variable
     The SYSTEM has a LOS60 random step variable
     The SYSTEM has a LOS62 random step variable
     The SYSTEM has a LOS67 random linear variable

     The SYSTEM has a RX.NO.DPT1 random step variable
     The SYSTEM has a RX.NO.DPT2.PRE random step variable
     The SYSTEM has a RX.NO.DPT2.POST random step variable

     The SYSTEM has an EMERGENCY random step variable
     The SYSTEM has a CASE.MIX.ERROR random step variable

     Define MTR.START, MTR.2191D, MTR.8140C, MTR.8325D, MTR.8327C,
         MTR.2191DO, MTR.8140CO, MTR.8325DO, MTR.8327C2, MTR.8140CO2,
         MTR.8327C3, MTR.8140CO3 as integer, stream 4 variables

     Define RX.NO.DPT1, RX.NO.DPT2.PRE, RX.NO.DPT2.POST as integer,
         stream 5 variables

     Define LOS5, LOS6, LOS7, LOS10, LOS11, LOS12, LOS13,
      LOS15, LOS16, LOS17, LOS29, LOS30, LOS31, LOS36, LOS37, LOS38,
      LOS42, LOS49, LOS50, LOS67  as real, stream 7 variables

     Define LOS9, LOS21, LOS23, LOS24, LOS28 , LOS35, LOS44, LOS60,
     LOS62 as integer, stream 7 variables

     Define EMERGENCY, CASE.MIX.ERROR as  real, stream 6 variable



'' Definition of processes
'' =======================

     Processes include GENERATE.DEPARTMENTS,
          RESET.STATISTICS, DPT.2192, DPT.8140, DPT.8327, DPT.8325,
          GENERATE.OR, PLANNING.TIME, ANCILLARY.SERVICE, GENERATE.MPS,
          MASTER.SCHEDULE

     Every FLOW.OF.PATIENT.THROUGH.DPT has a FP.DPT
     Define FP.DPT as a pointer variable

     Every GENERATE.PATIENTS has a GP.NO.OF.ADMISSIONS
     Define GP.NO.OF.ADMISSIONS as an integer variable
```

```

'' One time unit is one hour. All times scaled in hours
'' =====================================================
      Define hours to mean units


''Functions and routines
''======================
      Define RTOT.F as a text function


'' Statistics collection
''======================
      Accumulate AVG.UTILIZATION.DEPARTMENT as the mean of N.X.DEPARTMEN
      Tally DEV.UTILIZATION.DPT8140 as the std.dev. of OCC.DPT8140
      Tally DEV.UTILIZATION.DPT8327 as the std.dev. of OCC.DPT8327
      Tally TOTAL.END.TIME as the sum of END.TIME
      Tally AVG.LENGTH.OF.STAY as the mean,
            MAX.LENGTH.OF.STAY as the maximum,
            MIN.LENGTH.OF.STAY as the minimum,
            DEV.LENGTH.OF.STAY as the std.dev. of LENGTH.OF.STAY
       Tally AVG.PRE.LOS as the mean,
              DEV.PRE.LOS as the std.dev. of PRE.LENGTH
       Tally AVG.POST.LOS as the mean,
              DEV.POST.LOS as the std.dev. of POST.LENGTH
       Tally AVG.SURG.LOS as the mean,
              DEV.SURG.LOS as the std.dev. of SURG.LENGTH
       Tally AVG.PRE.LOS.104 as the mean,
              DEV.PRE.LOS.104 as the std.dev. of PRE.LOS.104
       Tally AVG.PRE.LOS.105 as the mean,
              DEV.PRE.LOS.105 as the std.dev. of PRE.LOS.105
       Tally AVG.PRE.LOS.106 as the mean,
              DEV.PRE.LOS.106 as the std.dev. of PRE.LOS.106
       Tally AVG.PRE.LOS.107 as the mean,
              DEV.PRE.LOS.107 as the std.dev. of PRE.LOS.107
       Tally AVG.SURG.LOS.104 as the mean,
              DEV.SURG.LOS.104 as the std.dev. of SURG.LOS.104
       Tally AVG.SURG.LOS.105 as the mean,
              DEV.SURG.LOS.105 as the std.dev. of SURG.LOS.105
       Tally AVG.SURG.LOS.106 as the mean,
              DEV.SURG.LOS.106 as the std.dev. of SURG.LOS.106
       Tally AVG.SURG.LOS.107 as the mean,
              DEV.SURG.LOS.107 as the std.dev. of SURG.LOS.107
       Tally AVG.POST.LOS.104 as the mean,
              DEV.POST.LOS.104 as the std.dev. of POST.LOS.104
       Tally AVG.POST.LOS.105 as the mean,
              DEV.POST.LOS.105 as the std.dev. of POST.LOS.105
       Tally AVG.POST.LOS.106 as the mean,
              DEV.POST.LOS.106 as the std.dev. of POST.LOS.106
       Tally AVG.POST.LOS.107 as the mean,
              DEV.POST.LOS.107 as the std.dev. of POST.LOS.107
       Tally AVG.TOTAL.LOS.104 as the mean,
              DEV.TOTAL.LOS.104 as the std.dev. of TOTAL.LOS.104
       Tally AVG.TOTAL.LOS.105 as the mean,
              DEV.TOTAL.LOS.105 as the std.dev. of TOTAL.LOS.105
```

```
     Tally AVG.TOTAL.LOS.106 as the mean,
           DEV.TOTAL.LOS.106 as the std.dev. of TOTAL.LOS.106
     Tally AVG.TOTAL.LOS.107 as the mean,
           DEV.TOTAL.LOS.107 as the std.dev. of TOTAL.LOS.107
    Tally AVG.PRE.RX as the mean of PRE.RX
    Tally AVG.SURG.RX as the mean of SURG.RX
    Tally AVG.POST.RX as the mean of POST.RX
    Tally AVG.LATENESS as the mean of LATENESS.TIME
    Tally DEV.LATENESS.TIME as the std.dev. of LATENESS.TIME
    Tally AVG.CURRENT.LAT as the mean of CURRENT.LATENESS
    Tally DEV.CURRENT.LATENESS as the std.dev. of CURRENT.LATENESS
    Tally AVG.SQUARE.CURLAT as the mean of SQUARE.CURLAT
    Tally TOTALS.RX as the daily sum of PLAN.RX.DAY
    Tally AVG.MPS.NUMBER as the mean of MPS.NUMBER
    Tally AVG1.MPS.NUMBER as the mean of MPS1.NUMBER
    Tally AVG.MAD.RX as the mean of MPD.RX.FOR.DAY
    Tally DEV.MAD.RX as the std.dev. of MPD.RX.FOR.DAY
    Tally AVG.MAD.BED as the mean of MPD.BED.FOR.DAY
    Tally DEV.MAD.BED as the std.dev. of MPD.BED.FOR.DAY
    Tally HISTO.ADM(0 to 20 by 1) as the histogram of NUMBER.OF.ADMISS
    Tally HISTO.DRG(104 to 107 by 1) as the histogram of DRG.HISTO
    Tally HISTO.MPS(0 to 5 by 1) as the histogram of NUMBER.OF.DISCHA
    Tally AVG.WAIT.BEFORE as the mean of WAIT.BEFORE.ADMISSION
    Tally DEV.WAIT.BEFORE as the std.dev. of WAIT.BEFORE.ADMISSION
    Tally AVG.BDAYS as the mean of BLOCKTIME
    Tally DEV.BDAYS as the std.dev. of BLOCKTIME
    Tally AVG.NO.BEDS as the mean of OCC.DPT8140
    Tally AVG.NO2.BEDS as the mean of OCC.DPT8327

'' Graphics
'' ========
Display variables include PLAN.RX.DAY
Display variables include ACTUAL.RX.DAY
Display variables include TOTAL.LOS.AVG
Display variables include NO.BEDS.ICU
Display variables include AVG.NO.BEDS.8140

End
```

```
''****
Main
''****

Call INITIALIZE

''Display PLAN.RX.DAY with "RX.GRF"
''Display ACTUAL.RX.DAY with "RX1.GRF"
''Display TOTAL.LOS.AVG with "LOS.GRF"
''Display AVG.NO.BEDS.8140 with "BEDS.GRF"
''Display NO.BEDS.ICU with "ICU.GRF"

BLOCK = 0

Activate a GENERATE.DEPARTMENTS now
Activate a GENERATE.MPS now
Activate a PLANNING.TIME now
Activate a RESET.STATISTICS now

Start simulation

Close unit 20
Close unit 21
Close unit 22
Close unit 31
Close unit 25
Close unit 26
Close unit 42
Close unit 45
Close unit 55
Close unit 60
Close unit 70
Close unit 80
Read as /
End
```

```
''*****************
Routine Initialize
''*****************

'' Reading input data
'' =================

    Open unit 40 for input, name is "DATA.DAT"
    Use unit 40 for input
    Read RUN.LENGTH
    start new record
    Read WARMUP.PERIOD
    start new record
    Read RESET.TIME
    start new record
    Read RESET.INTERVAL
    start new record
    Read START.STAT
    start new record
    Read PLANNING.HORIZON
    start new record
    Read NUMBER.OF.DEPARTMENTS
    start new record
    Read ICU.BEDS
    start new record
    Read P4
    start new record
    Read SI.RX3, SI.RX4
    start new record
    Read MTR.START
    start new record
    Read MTR.2191D
    start new record
    Read MTR.8140C
    start new record
    Read MTR.8325D
    start new record
    Read MTR.8327C
    start new record
    Read MTR.2191DO
    start new record
    Read MTR.8140CO
    start new record
    Read MTR.8325DO
    start new record
    Read MTR.8327C2
    start new record
    Read MTR.8140CO2
    start new record
    Read MTR.8327C3
    start new record
    Read MTR.8140CO3
    start new record
    Read LOS5
    start new record
```

```
Read LOS6
start new record
Read LOS7
start new record
Read LOS9
start new record
Read LOS10
start new record
Read LOS11
start new record
Read LOS12
start new record
Read LOS13
start new record
Read LOS15
start new record
Read LOS16
start new record
Read LOS17
start new record
Read LOS21
start new record
Read LOS23
start new record
Read LOS24
start new record
Read LOS28
start new record
Read LOS29
start new record
Read LOS30
start new record
Read LOS31
start new record
Read LOS35
start new record
Read LOS36
start new record
Read LOS37
start new record
Read LOS38
start new record
Read LOS42
start new record
Read LOS44
start new record
Read LOS49
start new record
Read LOS50
start new record
Read LOS60
start new record
Read LOS62
start new record
Read LOS67
```

```
    start new record
    Read RX.NO.DPT1
    start new record
    Read RX.NO.DPT2.PRE
    start new record
    Read RX.NO.DPT2.POST
    Close unit 40

Open unit 42 for input, name is "EXPERIMENT.DAT"
Use unit 42 for input
    Read PLANNING.PERIODICITY
    start new record
    Read EMERGENCY
    start new record
    Read CASE.MIX.ERROR
    start new record
    Read P1
    start new record
    Read P2
    start new record
    Read P3
    start new record
    Read P5
    start new record
    Read P6
    start new record
    Read NUMBER.FOR.OR
    Start new record
    Read DESIGN
    close unit 42

Open unit 45 for input, name is "SEED.DAT"
Use unit 45 for input
    Read SEED1
    start new record
    Read SEED2
    start new record
    Read SEED3
    start new record
    Read SEED4
    start new record
    Read SEED5
    start new record
    Read SEED6
    start new record
    Read SEED7
    start new record
    Read SEED8
    start new record
    Read SEED9
    start new record
    Read SEED10
    Close unit 45

SEED.V(1) = SEED1
```

```
SEED.V(2) = SEED2
SEED.V(3) = SEED3
SEED.V(4) = SEED4
SEED.V(5) = SEED5
SEED.V(6) = SEED6
SEED.V(7) = SEED7
SEED.V(8) = SEED8
SEED.V(9) = SEED9
SEED.V(10) = SEED10

'' Writing output data
'' ===================

Open unit 42 for output, name is "EXPERIMENT.DAT"
Use unit 42 for output
lines.v = 0

Open unit 45 for output, name is "SEED.DAT"
Use unit 45 for output
lines.v = 0

Open unit 20 for output, name is "RESULTAAT.DAT"
Use unit 20 for output
lines.v = 0
write as "Results of Simulation",/
write as "----------------------",/

Open unit 21 for output, name is "RESULT1.DAT"
Use unit 21 for output

Open unit 22 for output, name is "RESULT2.DAT"
Use unit 22 for output

Open unit 31 for output, name is "RESULT3.DAT"
Use unit 31 for output
Print 10 lines with SEED.V(1), SEED.V(2), SEED.V(3), SEED.V(4),
    SEED.V(5), SEED.V(6), SEED.V(7), SEED.V(8), SEED.V(9),
    SEED.V(10) thus
    ******************
    ******************
    ******************
    ******************
    ******************
    ******************
    ******************
    ******************
    ******************
    ******************

Open unit 25 for output, name is "OPERATING.RESULTS"
Use unit 25 for output
lines.v = 0
```

```
Open unit 26 for output, name is "LOS.DATA"
Use unit 26 for output
lines.v = 0


Open unit 55 for output, name is "TRACE.MPS"
Use unit 55 for output
lines.v = 0

Open unit 60 for output, name is "TRACE.DAT"
Use unit 60 for output
lines.v = 0

Open unit 70 for output, name is "MPS.RESULT"
Use unit 70 for output
lines.v = 0

Open unit 80 for output, name is "TRACE.DAY"
Use unit 80 for output
lines.v = 0

Use unit 6 for output
End
```

```
''*********************
Process PLANNING.TIME
''*********************

Define .N as real variables
Define .DAYCOUNTER as an integer variable

DAYCOUNTER = 0
DAYSCOUNTER = 0
.DAYCOUNTER = Int.f(time.v/24)

Until time.v >= (RUN.LENGTH*24)
    Do
        Let .N = Poisson.F(1.3,8)
        NUMBER.OF.ADMISSIONS = Int.f(.N)
        If NUMBER.OF.ADMISSIONS > 0
                Activate a GENERATE.PATIENTS giving NUMBER.OF.ADMISSI
        Endif
        Activate an ANCILLARY.SERVICE now
        DAYSCOUNTER = DAYSCOUNTER + 1
        DAYCOUNTER = DAYCOUNTER + 1
        .DAYCOUNTER = .DAYCOUNTER + 1
        TOTAL.LOS.AVG = AVG.LENGTH.OF.STAY
        If .DAYCOUNTER = PLANNING.PERIODICITY
            If time.v > (WARMUP.PERIOD + RESET.TIME) * 24
            Call MPS.DRG.104
            Endif
        .DAYCOUNTER = 0
        Endif
        NO.BEDS.ICU = N.X.DEPARTMENT(4)
        Wait 24 hours
    Loop
End
```

```
''*************************
Process ANCILLARY.SERVICE
''*************************

Define .DAY as a pointer variable
Define .X, .Y, .BED as real variables


For each department
    with DPT.ID(Department) = 1
    Find the first case
    If found
    .BED = .BED + N.X.DEPARTMENT(1)
    Endif


For each department
    with DPT.ID(Department) = 2
    Find the first case
    If found
    NO.BEDS.8140 = N.X.DEPARTMENT(2)
    AVG.NO.BEDS.8140 = NO.BEDS.8140
    .BED = .BED + N.X.DEPARTMENT(2)
    OCC.DPT8140 = N.X.DEPARTMENT(2)
    Endif

For each department
    with DPT.ID(Department) = 3
    Find the first case
    If found
        .X = N.X.DEPARTMENT(3) * SI.RX3
        .BED = .BED + N.X.DEPARTMENT(3)
    Endif

For each department
    with DPT.ID(Department) = 4
    Find the first case
    If found
        .Y = N.X.DEPARTMENT(4) * SI.RX4
        .BED = .BED + N.X.DEPARTMENT(4)
        OCC.DPT8327 = N.X.DEPARTMENT(4)
    Endif


For each .DAY in the MPS.DRG107
    with DAY.NUMBER(.DAY) = (Int.f(time.v/24))
    Find the first case
    If found,
        Remove .DAY from the MPS.DRG107
        Remove .DAY from the MPS.DRG104
        ACTUAL.RX.FOR.DAY(.DAY) = RX.NO.2 + RX.NO.8 + .X + .Y
        ACTUAL.BED.FOR.DAY(.DAY) = .BED
        If time.v >= (WARMUP.PERIOD + RESET.TIME + START.STAT)*24
            If (PLAN1.RX.FOR.DAY(.DAY) + PLAN.RX.FOR.DAY(.DAY)) <> 0
            MPD.RX.FOR.DAY = (ABS.f(PLAN1.RX.FOR.DAY(.DAY)
```

```
                    + PLAN.RX.FOR.DAY(.DAY) - ACTUAL.RX.FOR.DAY(.DAY))
                    * 100)/(PLAN1.RX.FOR.DAY(.DAY) +
                    PLAN.RX.FOR.DAY(.DAY))
                Else
                MPD.RX.FOR.DAY = 0
                Endif
                If (PLAN1.BED.FOR.DAY(.DAY) + PLAN.BED.FOR.DAY(.DAY))<> 0
                MPD.BED.FOR.DAY = (ABS.f(PLAN1.BED.FOR.DAY(.DAY)
                    + PLAN.BED.FOR.DAY(.DAY) - ACTUAL.BED.FOR.DAY(.DAY))
                    100) /(PLAN1.BED.FOR.DAY(.DAY) +
                    PLAN.BED.FOR.DAY(.DAY))
                Else
                MPD.BED.FOR.DAY = 0
                Endif
            Endif
            FIle .DAY in the MPS.DRG107
            File .DAY in the MPS.DRG104
            RX.NO.2 = 0
            RX.NO.8 = 0
            .X = 0
            .Y = 0
        Endif
    End
```

```
''**********************************************
Process Generate.Patients given NO.OF.ADMISSIONS
''**********************************************

    Define .PATIENT, .DAY as pointer variables
    Define .COUNTER as integer variables
    Define .X  as an integer variable


    .COUNTER = NO.OF.ADMISSIONS

        Until .COUNTER = 0
        Do
            Create a PATIENT called .PATIENT
            Add 1 to COUNT
            Subtract 1 from .COUNTER
            PATIENT.ID(.PATIENT) = COUNT
            Let .X = MTR.START
            DEPARTURE(.PATIENT) = .X
            OK.TEST(.PATIENT) = 0

            If EMERGENCY = 0
                PLAN.ADMISSION(.PATIENT) = time.v
                PLAN.ADMIT(.PATIENT) = PLAN.ADMISSION(.PATIENT)
                EMERG(.PATIENT) = 1
                Call WRITE.TRACE.LINE giving "patient",
                PATIENT.ID(.PATIENT), "patient emergency"
            else
                PLAN.ADMISSION(.PATIENT) =(2.71828**
                        (LOG.NORMAL.F(2.89,0.67,9))* 24) + time.v
                PLAN.ADMIT(.PATIENT) = PLAN.ADMISSION(.PATIENT)
            Endif

            If DEPARTURE(.PATIENT) = 1
                Let PATH(.PATIENT) = 1
            Endif

            If PATH(.PATIENT) = 1
                DRG(.PATIENT) = 104
                DRG.HISTO = DRG(.PATIENT)
            Else
                 DRG(.PATIENT) = 107
                 DRG.HISTO = DRG(.PATIENT)
            Endif

            If CASE.MIX.ERROR = 0
                If DRG(.PATIENT) = 104
                   DRG(.PATIENT) = 107
                   Call WRITE.TRACE.LINE giving "patient",
                   PATIENT.ID(.PATIENT), patient with 104 is
                   treated as 107"
                Else
                    DRG(.PATIENT) = 104
                    Call WRITE.TRACE.LINE giving "patient",
                    PATIENT.ID(.PATIENT), "patient with 107 is
```

```
                      treated as 104"
                  Endif
              Endif

           Call WRITE.TRACE.LINE giving "patient",
           PATIENT.ID(.PATIENT),"arrival queue"
           File .PATIENT in the ARRIVAL.QUEUE
           File .PATIENT in the LIST.OF.PATIENTS
           Activate a MASTER.SCHEDULE now
           Activate a FLOW.OF.PATIENT.THROUGH.DPT now

          Loop
         .COUNTER = 0
End
```

```
''************************
Process MASTER.SCHEDULE
''************************

Define .PATIENT, .DAY as pointer variables

Remove the first .PATIENT from the ARRIVAL.QUEUE
Remove .PATIENT from the LIST.OF.PATIENTS

Select case DRG(.PATIENT)
    Case 104
    For each .DAY in the MPS.DRG104
        with DAY.NUMBER(.DAY) = Int.f(PLAN.ADMISSION(.PATIENT)/24)
                + AVGLOS.TOTAL.104
            Find the first case
            If found,
                Remove .DAY from MPS.DRG104
                DISCHARGE.TIME(.PATIENT) = DAY.NUMBER(.DAY)
                DISCHARGE.TIME.RE(.PATIENT) = DAY.NUMBER(.DAY)
                Add 1 to NO1.OF.DISCHARGES(.DAY)
                Call WRITE.TRACE.DAY giving "day", DAY.NUMBER(.DAY),
                PATIENT.ID(.PATIENT), "scheduled DUE DATE of DRG104"
                File .DAY in MPS.DRG104
                Call WRITE.TRACE.LINE giving "patient",
                PATIENT.ID(.PATIENT),"patient in MPS.DRG104"
            Endif

''    Case 105
''    For each .DAY in the MPS.DRG105
''        with DAY.NUMBER(.DAY) = Int.f(time.v/24) + AVGLOS.TOTAL.105
''        Find the first case
''            If found,
''                Remove .DAY from MPS.DRG105
''                Add 1 to NO.OF.DISCHARGES(.DAY)
''                File .DAY in MPS.DRG105
''                Call WRITE.TRACE.LINE giving "patient",
''                PATIENT.ID(.PATIENT),"patient in MPS.DRG105"
''             Endif

''    Case 106
''    For each .DAY in the MPS.DRG106
''        with DAY.NUMBER(.DAY) = Int.f(time.v/24) + AVGLOS.TOTAL.106
''        Find the first case
''            If found,
''                Remove .DAY from MPS.DRG106
''                Add 1 to NO.OF.DISCHARGES(.DAY)
''                File .DAY in MPS.DRG106
''                Call WRITE.TRACE.LINE giving "patient",
''                PATIENT.ID(.PATIENT), "patient in MPS.DRG106"
''            Endif

    Case 107
    For each .DAY in the MPS.DRG107
        with DAY.NUMBER(.DAY) = Int.f(PLAN.ADMISSION(.PATIENT)/24)
                + AVGLOS.TOTAL.107
```

```
            Find the first case
            If found,
                Remove .DAY from MPS.DRG107
                DISCHARGE.TIME(.PATIENT) = DAY.NUMBER(.DAY)
                DISCHARGE.TIME.RE(.PATIENT) = DAY.NUMBER(.DAY)
                Add 1 to NO.OF.DISCHARGES(.DAY)
                Call WRITE.TRACE.DAY giving "day", DAY.NUMBER(.DAY),
                PATIENT.ID(.PATIENT), "Scheduled DUE DATE of DRG107"
                File .DAY in MPS.DRG107
                Call WRITE.TRACE.LINE giving "patient", PATIENT.ID(.P
                "patient in MPS.DRG107"
            Endif
    Endselect

File .PATIENT in the ARRIVAL.QUEUE
File .PATIENT in the LIST.OF.PATIENTS
End
```

```
''**********************************
Process FLOW.OF.PATIENT.THROUGH.DPT
''**********************************
    Define .PATIENT as pointer variable


Until ARRIVAL.QUEUE is empty
    Do
        Remove first .PATIENT from ARRIVAL.QUEUE
        If PLAN.ADMIT(.PATIENT) >= time.v
            .X = PLAN.ADMIT(.PATIENT) - time.v
            Call WRITE.TRACE.LINE giving "patient",
            PATIENT.ID(.PATIENT), "patient is scheduled for admission
            Work .X hours
        Endif
    Loop
    Call WRITE.TRACE.LINE giving "patient", PATIENT.ID(.PATIENT),
    "patient leaves arrival queue"
    ARRIVAL.TIME(.PATIENT) = time.v

    If DEPARTURE(.PATIENT) = 1
       For each DEPARTMENT,
       with DPT.ID(DEPARTMENT) = 1
       Find the first case
       If found,
          File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
       Endif
       Activate a DPT.2192 now
    Else
       If DEPARTURE(.PATIENT) = 2
          For each DEPARTMENT,
          with DPT.ID(DEPARTMENT) = 2
          Find the first case
          If found,
             File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
          Endif
          Activate a DPT.8140 now
       Else
          If DEPARTURE(.PATIENT) = 3
             For each DEPARTMENT,
             with DPT.ID(DEPARTMENT) = 3
             Find the first case
             If found,
                File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
             Endif
             Activate a DPT.8325 now
          Else
             For each DEPARTMENT,
             with DPT.ID(DEPARTMENT) = 4
             Find the first case
             If found,
                BLOCK.TIME(.PATIENT) = time.v
                File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
             Endif
             Activate a DPT.8327 now
```

```
            Endif
         Endif
      Endif
End
```

```
''****************
Process DPT.2192
''****************

Define .PATIENT as a pointer variable
Define  .X, .Y as real variables
Define .Z  as an integer variable

For each DEPARTMENT,
    With DPT.ID(DEPARTMENT) = 1
    Find the first case
    If found
        IF DEPARTMENT.QUEUE(DEPARTMENT) is not empty
            Request 1 DEPARTMENT(1)
            Remove the first .PATIENT from
                DEPARTMENT.QUEUE(DEPARTMENT)
            .PATIENT = .PATIENT
            Call WRITE.TRACE.LINE giving "patient",
            PATIENT.ID(.PATIENT), "patient in department 2191"
            Let .Z = RX.NO.DPT1
            RX = .Z
            RXS(.PATIENT) = .Z
            TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT) + .Z
            Select case DEPARTURE(.PATIENT)
            Case 1
                PATH(.PATIENT) = 1
                Let .Y = MTR.2191D
                Let ARRIVAL(.PATIENT) = .Y
                If ARRIVAL(.PATIENT) = 2
                    DEPARTURE(.PATIENT) = 2
                    IF P4 = 1
                       Let .X = NORMAL.F(137.56,108.61*P5,10)
                       If .X <= 3
                           .X = 3
                       Endif
                    Else
                       Let .X = LOS5
                    Endif
                    LOS(.PATIENT) = time.v + .X
                    SCHEDULE.TIME(.PATIENT) = .X
                    Call WRITE.TRACE.LINE giving "patient",
                    PATIENT.ID(.PATIENT),"patient in matrix 5"
                    If RXS(.PATIENT) <> 0
                        TIME.INT(.PATIENT) = SCHEDULE.TIME(.PATIENT)/
                        RXS(.PATIENT)
                        RX.NO.2 = RX.NO.2 + 1
                        Call WRITE.TRACE.LINE giving "patient",
                        PATIENT.ID(.PATIENT), "patient: RX in DPT.219
                        Until time.v >= LOS(.PATIENT)-1
                        Do
                          work TIME.INT(.PATIENT) hours
                          let RX.NO.2 = RX.NO.2 + 1
                          Call WRITE.TRACE.LINE giving "patient",
                          PATIENT.ID(.PATIENT), "patient: RX in DPT.2
                        Loop
```

```
                Else
                   work .X hours
                Endif
                Call WRITE.TRACE.LINE giving "patient",
                PATIENT.ID(.PATIENT),"patient out matrix 5"
                Relinquish 1 DEPARTMENT(1)
               .PATIENT = .PATIENT
               For each DEPARTMENT
               with DPT.ID(DEPARTMENT) = 2
               Find the first case
               If found
                  File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
               Endif
               Activate a DPT.8140 now
           Else
             If ARRIVAL(.PATIENT) = 3
                DEPARTURE(.PATIENT) = 3
                Let .X = LOS6
                LOS(.PATIENT) = time.v + .X
                Call WRITE.TRACE.LINE giving "patient",
                PATIENT.ID(.PATIENT), "patient in matrix 6"
                SCHEDULE.TIME(.PATIENT) = .X
                If RXS(.PATIENT) <> 0
                   TIME.INT(.PATIENT) = SCHEDULE.TIME(.PATIENT)/
                       RXS(.PATIENT)
                   RX.NO.2 = RX.NO.2 + 1
                   Call WRITE.TRACE.LINE giving "patient",
                   PATIENT.ID(.PATIENT), "patient: RX in DPT.219
                   Until time.v >= LOS(.PATIENT)-1
                   Do
                      Work TIME.INT(.PATIENT) hours
                      Let RX.NO.2 = RX.NO.2 + 1
                      Call WRITE.TRACE.LINE giving "patient",
                      PATIENT.ID(.PATIENT),"patient: RX in DPT.2
                   Loop
                Else
                   work .X hours
                Endif
                Call WRITE.TRACE.LINE giving "patient",
                PATIENT.ID(.PATIENT),"patient out matrix 6"
                Relinquish 1 DEPARTMENT(1)
                .PATIENT = .PATIENT
                For each DEPARTMENT
                   with DPT.ID(DEPARTMENT) = 3
                   Find the first case
                   If found
                       File .PATIENT in DEPARTMENT.QUEUE(DEPARTM
                   Endif
                Activate a DPT.8325 now
             Else
                DEPARTURE(.PATIENT) = 4
                Let .X = LOS7
                LOS(.PATIENT) = time.v + .X
                Call WRITE.TRACE.LINE giving "patient",
                PATIENT.ID(.PATIENT),"patient in matrix 7"
```

```
         SCHEDULE.TIME(.PATIENT) = .X
         If RXS(.PATIENT) <> 0
            TIME.INT(.PATIENT) = SCHEDULE.TIME(.PATIENT)/
            RXS(.PATIENT)
            RX.NO.2 = RX.NO.2 + 1
            Call WRITE.TRACE.LINE giving "patient",
            PATIENT.ID(.PATIENT),"patient: RX in DPT.2191
            Until time.v >= LOS(.PATIENT)-1
            Do
              work TIME.INT(.PATIENT) hours
              Let RX.NO.2 = RX.NO.2 + 1
              Call WRITE.TRACE.LINE giving "patient",
              PATIENT.ID(.PATIENT),"patient: RX in DPT.21
            Loop
         Else
            work .X hours
         Endif
         Call WRITE.TRACE.LINE giving "patient",
         PATIENT.ID(.PATIENT),"patient out matrix 7"
         Relinquish 1 DEPARTMENT(1)
         .PATIENT = .PATIENT
         BLOCK.TIME(.PATIENT) = time.v
         Call WRITE.TRACE.LINE giving "patient",
         PATIENT.ID(.PATIENT),"patient in the department
         queue before 8327"
         For each DEPARTMENT
            with DPT.ID(DEPARTMENT) = 4
            Find the first case
            If found,
              File .PATIENT in the DEPARTMENT.QUEUE(DEPAR
              Activate a DPT.8327 now
            Endif
      Endif
    Endif

Case 5
    Let .Y = MTR.2191DO
    Let ARRIVAL(.PATIENT) = .Y
    If ARRIVAL(.PATIENT) = 6
        DEPARTURE(.PATIENT) = 6
        Let .X = LOS21
        Call WRITE.TRACE.LINE giving "patient",
        PATIENT.ID(.PATIENT),"patient in matrix 21"
        SCHEDULE.TIME(.PATIENT) = .X
        If RXS(.PATIENT) <> 0
            TIME.INT(.PATIENT) = SCHEDULE.TIME(.PATIENT)/
                RXS(.PATIENT)
            RX.NO.2 = RX.NO.2 + 1
            Call WRITE.TRACE.LINE giving "patient",
            PATIENT.ID(.PATIENT),"patient: RX in DPT.2191
            Until time.v >= LOS(.PATIENT)-1
            Do
              work TIME.INT(.PATIENT) hour
              Let RX.NO.2 = RX.NO.2 + 1
              Call WRITE.TRACE.LINE giving "patient",
```

```
          PATIENT.ID(.PATIENT),"patient: RX in DPT.21
        Loop
    Else
        work .X hours
    Endif
    Call WRITE.TRACE.LINE giving "patient",
    PATIENT.ID(.PATIENT),"patient out matrix 21"
    Relinquish 1 DEPARTMENT(1)
    .PATIENT = .PATIENT
    For each DEPARTMENT
        with DPT.ID(DEPARTMENT) = 2
        Find the first case
        If found
            File .PATIENT in DEPARTMENT.QUEUE(DEPARTM
        Endif
    Activate a DPT.8140 now
Else
  If ARRIVAL(.PATIENT) = 8
     DEPARTURE(.PATIENT) = 8
     Let .X = LOS23
     Call WRITE.TRACE.LINE giving "patient",
     PATIENT.ID(.PATIENT),"patient in matrix 23"
     SCHEDULE.TIME(.PATIENT) = .X
     If RXS(.PATIENT) <> 0
        TIME.INT(.PATIENT) = SCHEDULE.TIME(.PATIENT)/
        RXS(.PATIENT)
        RX.NO.2 = RX.NO.2 + 1
        Call WRITE.TRACE.LINE giving "patient",
        PATIENT.ID(.PATIENT),"patient: RX in DPT.2191
        Until time.v >= LOS(.PATIENT)-1
        Do
          work TIME.INT(.PATIENT) hours
          Let RX.NO.2 = RX.NO.2 + 1
          Call WRITE.TRACE.LINE giving "patient",
          PATIENT.ID(.PATIENT),"patient: RX in DPT.21
        Loop
     Else
        work .X hours
     Endif
     Call WRITE.TRACE.LINE giving "patient",
     PATIENT.ID(.PATIENT),"patient out matrix 23"
     Relinquish 1 DEPARTMENT(1)
     .PATIENT = .PATIENT
     BLOCK.TIME(.PATIENT) = time.v
     Call WRITE.TRACE.LINE giving "patient",
     PATIENT.ID(.PATIENT),"patient in the department
     queue before DPT.8327"
     For each DEPARTMENT
     with DPT.ID(DEPARTMENT) = 4
     Find the first case
     If found,
       File .PATIENT in the DEPARTMENT.QUEUE(DEPARTMEN
       Activate a DPT.8327 now
     Endif
  Else
```

```
                     DEPARTURE(.PATIENT) = 20
                     Let .X = LOS24
                     Call WRITE.TRACE.LINE giving "patient",
                     PATIENT.ID(.PATIENT),"patient in matrix 24"
                     SCHEDULE.TIME(.PATIENT) = .X
                     If RXS(.PATIENT) <> 0
                        TIME.INT(.PATIENT) = SCHEDULE.TIME(.PATIENT)/
                            RXS(.PATIENT)
                        RX.NO.2 = RX.NO.2 + 1
                        Call WRITE.TRACE.LINE giving "patient",
                        PATIENT.ID(.PATIENT),"patient: RX in DPT.2191"
                        Until time.v >= LOS(.PATIENT)-1
                        Do
                          work TIME.INT(.PATIENT) hours
                          Let RX.NO.2 = RX.NO.2 + 1
                          Call WRITE.TRACE.LINE giving "patient",
                          PATIENT.ID(.PATIENT),"patient: RX in DPT.219
                        Loop
                     Else
                        work .X hours
                     Endif
                     Call WRITE.TRACE.LINE giving "patient",
                     PATIENT.ID(.PATIENT),"patient out matrix 24"
                     Relinquish 1 DEPARTMENT(1)
                     .PATIENT = .PATIENT
                     File .PATIENT in the DONE.QUEUE
                     If DONE.QUEUE is not empty
                        Call PATIENT.DONE
                     Endif
                  Endif
               Endif
           Endselect
        Endif
    Endif
End
```

```
''****************
Process DPT.8325
''****************

Define .PATIENT as a pointer variable
Define .X, .Y  as real variables


For each Department,
  With DPT.ID(DEPARTMENT) = 3
  Find the first case
  If found
    If DEPARTMENT.QUEUE(DEPARTMENT) is not empty
       Request 1 DEPARTMENT(3)
       Remove the first .PATIENT from DEPARTMENT.QUEUE(DEPARTMENT)
       .PATIENT = .PATIENT
        Call WRITE.TRACE.LINE giving "patient", PATIENT.ID(.PATIENT),
       "patient in department 8325"
       Select case DEPARTURE(.PATIENT)
       Case 3
          Let .Y = MTR.8325D
          Let ARRIVAL(.PATIENT) = .Y
          If ARRIVAL(.PATIENT) = 1
             DEPARTURE(.PATIENT) = 1
             Let .X = LOS11
             TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT)+((.X/24)*SI.RX3)
             LOS(.PATIENT) = time.v + .X
             RX.NO.85 = RX.NO.85 + SI.RX3
             Call WRITE.TRACE.LINE giving "patient",
             PATIENT.ID(.PATIENT), "RX for patient in DPT.8325"
             Call WRITE.TRACE.LINE giving "patient",
             PATIENT.ID(.PATIENT),"patient in matrix 11"
             Work .X hours
             Call WRITE.TRACE.LINE giving "patient",
             PATIENT.ID(.PATIENT),"patient out matrix 11"
             Relinquish 1 DEPARTMENT(3)
             .PATIENT = .PATIENT
             For each DEPARTMENT
                with DPT.ID(DEPARTMENT) = 1
                Find the first case
                If found
                  File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
                Endif
                Activate a DPT.2192 now
          Else
             If ARRIVAL(.PATIENT) = 2
                DEPARTURE(.PATIENT) = 2
                Let .X = LOS12
                TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT)+
                    ((.X/24)*SI.RX3)
                LOS(.PATIENT) = time.v + .X
                RX.NO.85 = RX.NO.85 + SI.RX3
                Call WRITE.TRACE.LINE giving "patient",
                PATIENT.ID(.PATIENT), "RX for patient in DPT.8325"
                Call WRITE.TRACE.LINE giving "patient",
```

```
            PATIENT.ID(.PATIENT),"patient in matrix 12"
            Work .X hours
            Call WRITE.TRACE.LINE giving "patient",
            PATIENT.ID(.PATIENT),"patient out matrix 12"
            Relinquish 1 DEPARTMENT(3)
            .PATIENT = .PATIENT
            For each DEPARTMENT
               with DPT.ID(DEPARTMENT) = 2
               Find the first case
               If found
                 File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
               Endif
            Activate a DPT.8140 now
         Else
            DEPARTURE(.PATIENT) = 4
            Let .X = LOS13
            TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT)+((.X/24)
                *SI.RX3)
            LOS(.PATIENT) = time.v + .X
            RX.NO.85 = RX.NO.85 + SI.RX3
            Call WRITE.TRACE.LINE giving "patient",
            PATIENT.ID(.PATIENT), "RX for patient in DPT.8325"
            Call WRITE.TRACE.LINE giving "patient",
            PATIENT.ID(.PATIENT),"patient in matrix 13"
            Work .X hours
            Call WRITE.TRACE.LINE giving "patient",
            PATIENT.ID(.PATIENT),"patient out matrix 13"
            Relinquish 1 DEPARTMENT(3)
            .PATIENT = .PATIENT
            BLOCK.TIME(.PATIENT) = time.v
            Call WRITE.TRACE.LINE giving "patient",
            PATIENT.ID(.PATIENT),"patient in the department
            queue before 8327"
            For each DEPARTMENT
              with DPT.ID(DEPARTMENT) = 4
              Find the first case
              If found
                File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
                Activate a DPT.8327 now
              Endif
         Endif
      Endif
   Case 7
      Let .Y = MTR.8325DO
      Let ARRIVAL(.PATIENT) = .Y
      If ARRIVAL(.PATIENT) = 5
         DEPARTURE(.PATIENT) = 5
         Let .X = LOS35
         TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT) +
         ((.X/24)*SI.RX3)
         RX.NO.85 = RX.NO.85 + SI.RX3
         Call WRITE.TRACE.LINE giving "patient",
          PATIENT.ID(.PATIENT), "RX for patient in DPT.8325"
         Call WRITE.TRACE.LINE giving "patient",
          PATIENT.ID(.PATIENT),"patient in matrix 35"
```

```
            Work .X hours
            Call WRITE.TRACE.LINE giving "patient",
             PATIENT.ID(.PATIENT), "patient out matrix 35"
            Relinquish 1 DEPARTMENT(3)
            .PATIENT = .PATIENT
            For each DEPARTMENT
               with DPT.ID(DEPARTMENT) = 1
               Find the first case
               If found
                 File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
               Endif
               Activate a DPT.2192 now
         Else
            If ARRIVAL(.PATIENT) = 6
               DEPARTURE(.PATIENT) = 6
               Let .X = LOS36
               TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT) +
                    ((.X/24)*SI.RX3)
               RX.NO.85 = RX.NO.85 + SI.RX3
               Call WRITE.TRACE.LINE giving "patient",
               PATIENT.ID(.PATIENT), "RX for patient in DPT.8325"
               Call WRITE.TRACE.LINE giving "patient",
               PATIENT.ID(.PATIENT),"patient in matrix 36"
               Work .X hours
               Call WRITE.TRACE.LINE giving "patient",
               PATIENT.ID(.PATIENT),"patient out matrix 36"
               Relinquish 1 DEPARTMENT(3)
               .PATIENT = .PATIENT
               For each DEPARTMENT
                  with DPT.ID(DEPARTMENT) = 2
                  Find the first case
                  If found
                     File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
                  Endif
                  Activate a DPT.8140 now
            Else
               If ARRIVAL(.PATIENT) = 8
                  DEPARTURE(.PATIENT) = 8
                  Let .X = LOS37
                  TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT) +
                       ((.X/24)*SI.RX3)
                  RX.NO.85 = RX.NO.85 + SI.RX3
                  Call WRITE.TRACE.LINE giving "patient",
                   PATIENT.ID(.PATIENT), "RX for patient in DPT.8325"
                  Call WRITE.TRACE.LINE giving "patient",
                   PATIENT.ID(.PATIENT),"patient in matrix 37"
                  Work .X hours
                  Call WRITE.TRACE.LINE giving "patient",
                   PATIENT.ID(.PATIENT),"patient out matrix 37"
                  Relinquish 1 DEPARTMENT(3)
                  .PATIENT = .PATIENT
                  BLOCK.TIME(.PATIENT) = time.v
                  Call WRITE.TRACE.LINE giving "patient",
                   PATIENT.ID(.PATIENT),"patient in the department
                   queue before 8327"
```

```
                   For each DEPARTMENT
                      with DPT.ID(DEPARTMENT) = 4
                      Find the first case
                      If found
                        File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
                        Activate a DPT.8327 now
                      Endif
                Else
                   DEPARTURE(.PATIENT) = 20
                   Let .X = LOS38
                   TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT) +
                        ((.X/24)*SI.RX3)
                   RX.NO.85 = RX.NO.85 + SI.RX3
                   Call WRITE.TRACE.LINE giving "patient",
                    PATIENT.ID(.PATIENT), "RX for patient in DPT.8325"
                   Call WRITE.TRACE.LINE giving "patient",
                    PATIENT.ID(.PATIENT),"patient in matrix 38"
                   Work .X hours
                   Call WRITE.TRACE.LINE giving "patient",
                    PATIENT.ID(.PATIENT),"patient out matrix 38"
                   Relinquish 1 DEPARTMENT(3)
                   .PATIENT = .PATIENT
                   File .PATIENT in the DONE.QUEUE
                   If DONE.QUEUE is not empty
                      Call PATIENT.DONE
                   Endif
                Endif
             Endif
          Endif
       Endselect
     Endif
  Endif
End
```

```
''****************
Process DPT.8140
''****************

Define .PATIENT as a pointer variable
Define .X, .Y as real variables
Define .Z as integer variables

For each DEPARTMENT
with DPT.ID(DEPARTMENT) = 2
Find the first case
  If found
     If DEPARTMENT.QUEUE(DEPARTMENT) is not empty
        Remove the first .PATIENT from DEPARTMENT.QUEUE(DEPARTMENT)
        Request 1 DEPARTMENT(2)
        .PATIENT = .PATIENT
        Call WRITE.TRACE.LINE giving "patient", PATIENT.ID(.PATIENT),
        "patient in department 8140"
        Select case DEPARTURE(.PATIENT)

        Case 2
           Let .Y = MTR.8140C
           Let .Z = RX.NO.DPT2.PRE
           RX = .Z
           RXS(.PATIENT) = .Z
           TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT) + .Z
           Let ARRIVAL(.PATIENT) = .Y
           If ARRIVAL(.PATIENT) = 3
              DEPARTURE(.PATIENT) = 3
              Let .X = LOS9
              LOS(.PATIENT) = time.v + .X
              SCHEDULE.TIME(.PATIENT) = .X
              Call WRITE.TRACE.LINE giving "patient",
               PATIENT.ID(.PATIENT),"patient in matrix 9"
              If RXS(.PATIENT) <> 0
                 TIME.INT(.PATIENT) = SCHEDULE.TIME(.PATIENT)/
                        RXS(.PATIENT)
                 RX.NO.2 = RX.NO.2 + 1
                 Call WRITE.TRACE.LINE giving "patient",
                  PATIENT.ID(.PATIENT),"patient: RX in DPT.8140"
                 Until time.v >= LOS(.PATIENT)-1
                 Do
                    work TIME.INT(.PATIENT) hours
                    Let RX.NO.2 = RX.NO.2 + 1
                    Call WRITE.TRACE.LINE giving "patient",
                     PATIENT.ID(.PATIENT),"patient: RX in DPT.8140"
                 Loop
              Else
                 work .X hours
              Endif
              Call WRITE.TRACE.LINE giving "patient",
               PATIENT.ID(.PATIENT),"patient out matrix 9"
              Relinquish 1 DEPARTMENT(2)
              .PATIENT = .PATIENT
              For each DEPARTMENT
```

```
         with DPT.ID(DEPARTMENT) = 3
         Find the first case
         If found
            File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
         Endif
         Activate a DPT.8325 now
   Else
         DEPARTURE(.PATIENT) = 4
         If P4 = 1
            Let .X = NORMAL.F(54.9,44.26*P5,1)
            If .X <= 1
               Let .X = 45
            Endif
         Else
            Let .X = LOS10
         Endif
         LOS(.PATIENT) = time.v + .X
         SCHEDULE.TIME(.PATIENT) = .X
         Call WRITE.TRACE.LINE giving "patient",
          PATIENT.ID(.PATIENT),"patient in matrix 10"
         If RXS(.PATIENT) <> 0
            TIME.INT(.PATIENT) = SCHEDULE.TIME(.PATIENT)/
                    RXS(.PATIENT)
            RX.NO.2 = RX.NO.2 + 1
            Call WRITE.TRACE.LINE giving "patient",
             PATIENT.ID(.PATIENT), "patient: RX in DPT.8140"
            Until time.v >= LOS(.PATIENT)-1
            Do
               work TIME.INT(.PATIENT) hours
               Let RX.NO.2 = RX.NO.2 + 1
               Call WRITE.TRACE.LINE giving "patient",
                PATIENT.ID(.PATIENT),"patient: RX in DPT.8140"
            Loop
         Else
            work .X hours
         Endif
         Call WRITE.TRACE.LINE giving "patient",
          PATIENT.ID(.PATIENT),"patient out matrix 10"
         Relinquish 1 DEPARTMENT(2)
         .PATIENT = .PATIENT
         BLOCK.TIME(.PATIENT) = time.v
         Call WRITE.TRACE.LINE giving "patient",
          PATIENT.ID(.PATIENT),"patient in the department
          queue before 8327"
         For each DEPARTMENT
         with DPT.ID(DEPARTMENT) = 4
         Find the first case
            If found
               File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
               Activate a DPT.8327 now
            Endif
   Endif

Case 6
   Let .Y = MTR.8140CO
```

```
Let .Z = RX.NO.DPT2.POST
RX = .Z
RXS(.PATIENT) = .Z
Let TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT) + .Z
Let ARRIVAL(.PATIENT) = .Y
If ARRIVAL(.PATIENT) = 5
   DEPARTURE(.PATIENT) = 5
   Let .X = LOS28
   LOS(.PATIENT) = time.v + .X
   SCHEDULE.TIME(.PATIENT) = .X
   Call WRITE.TRACE.LINE giving "patient",
   PATIENT.ID(.PATIENT), "patient in matrix 28"
   If RXS(.PATIENT) <> 0
      TIME.INT(.PATIENT) = SCHEDULE.TIME(.PATIENT)/
             RXS(.PATIENT)
      RX.NO.2 = RX.NO.2 + 1
      Call WRITE.TRACE.LINE giving "patient",
       PATIENT.ID(.PATIENT),"patient: RX in DPT.8140"
      Until time.v >= LOS(.PATIENT)-1
      Do
        work TIME.INT(.PATIENT) hours
        Let RX.NO.2 = RX.NO.2 + 1
        Call WRITE.TRACE.LINE giving "patient",
         PATIENT.ID(.PATIENT),"patient: RX in DPT.8140"
      Loop
   Else
      work .X hours
   Endif
   Call WRITE.TRACE.LINE giving "patient",
   PATIENT.ID(.PATIENT),"patient out matrix 28"
   Relinquish 1 DEPARTMENT(2)
   .PATIENT = .PATIENT
   For each DEPARTMENT
      with DPT.ID(DEPARTMENT) = 1
      Find the first case
      If found
         File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
      Endif
      Activate a DPT.2192 now
Else
   If ARRIVAL(.PATIENT) = 7
      DEPARTURE(.PATIENT) = 7
      Let .X = LOS29
      LOS(.PATIENT) = time.v + .X
      SCHEDULE.TIME(.PATIENT)= .X
      Call WRITE.TRACE.LINE giving "patient",
       PATIENT.ID(.PATIENT),"patient in matrix 29"
      If RXS(.PATIENT) <> 0
         TIME.INT(.PATIENT) = SCHEDULE.TIME(.PATIENT)/
                 RXS(.PATIENT)
         RX.NO.2 = RX.NO.2 + 1
         Call WRITE.TRACE.LINE giving "patient",
          PATIENT.ID(.PATIENT),"patient: RX in DPT.8140"
         Until time.v >= LOS(.PATIENT)-1
         Do
```

```
          work TIME.INT(.PATIENT) hours
          Let RX.NO.2 = RX.NO.2 + 1
          Call WRITE.TRACE.LINE giving "patient",
           PATIENT.ID(.PATIENT),"patient: RX in DPT.8140'
       Loop
    Else
       work .X hours
    Endif
    Call WRITE.TRACE.LINE giving "patient",
     PATIENT.ID(.PATIENT),"patient out matrix 29"
    Relinquish 1 DEPARTMENT(2)
    .PATIENT = .PATIENT
    For each DEPARTMENT
    with DPT.ID(DEPARTMENT) = 3
    Find the first case
      If found
         File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
      Endif
      Activate a DPT.8325 now
Else
   If ARRIVAL(.PATIENT) = 8
      DEPARTURE(.PATIENT) = 8
      If P4 = 1
         Let .X = 2.71828**(LOG.NORMAL.F(5.34,0.35*P5,2))
      Else
         Let .X = LOS30
      Endif
      LOS(.PATIENT) = time.v + .X
      SCHEDULE.TIME(.PATIENT) = .X
      Call WRITE.TRACE.LINE giving "patient",
       PATIENT.ID(.PATIENT),"patient in matrix 30"
      If RXS(.PATIENT) <> 0
         TIME.INT(.PATIENT) = SCHEDULE.TIME(.PATIENT)/
               RXS(.PATIENT)
         RX.NO.2 = RX.NO.2 + 1
         Call WRITE.TRACE.LINE giving "patient",
         PATIENT.ID(.PATIENT),"patient: RX in DPT.8140"
         Until time.v >= LOS(.PATIENT)-1
         Do
           work TIME.INT(.PATIENT) hours
           Let RX.NO.2 = RX.NO.2 + 1
           Call WRITE.TRACE.LINE giving "patient",
            PATIENT.ID(.PATIENT),"patient: RX in DPT.8140
         Loop
      Else
         work .X hours
      Endif
      Call WRITE.TRACE.LINE giving "patient",
       PATIENT.ID(.PATIENT),"patient out matrix 30"
      Relinquish 1 DEPARTMENT(2)
      .PATIENT = .PATIENT
      BLOCK.TIME(.PATIENT) = time.v
      Call WRITE.TRACE.LINE giving "patient",
       PATIENT.ID(.PATIENT),"patient in the department
       queue before 8327"
```

```
                  For each DEPARTMENT
                     with DPT.ID(DEPARTMENT) = 4
                     Find the first case
                        If found
                           File .PATIENT in DEPARTMENT.QUEUE(DEPARTME
                           Activate a DPT.8327 now
                        Endif
               Else
                  DEPARTURE(.PATIENT) = 20
                  Let .X = LOS31
                  LOS(.PATIENT) = time.v + .X
                  SCHEDULE.TIME(.PATIENT) = .X
                  Call WRITE.TRACE.LINE giving "patient",
                   PATIENT.ID(.PATIENT), "patient in matrix 31"
                  If RXS(.PATIENT) <> 0
                     TIME.INT(.PATIENT) = SCHEDULE.TIME(.PATIENT)/
                           RXS(.PATIENT)
                     RX.NO.2 = RX.NO.2 + 1
                     Call WRITE.TRACE.LINE giving "patient",
                       PATIENT.ID(.PATIENT),"patient: RX in DPT.8140'
                     Until time.v >= LOS(.PATIENT)-1
                     Do
                       work TIME.INT(.PATIENT) hours
                       Let RX.NO.2 = RX.NO.2 + 1
                       Call WRITE.TRACE.LINE giving "patient",
                        PATIENT.ID(.PATIENT), "patient: RX in DPT.814
                    Loop
                 Else
                    work .X hours
                 Endif
                 Call WRITE.TRACE.LINE giving "patient",
                  PATIENT.ID(.PATIENT),"patient out matrix 31"
                 Relinquish 1 DEPARTMENT(2)
                 .PATIENT = .PATIENT
                 File .PATIENT in the DONE.QUEUE
                 If DONE.QUEUE is not empty
                    Call PATIENT.DONE
                 Endif
               Endif
            Endif
         Endif

      Case 9
         Let .Y = MTR.8140CO2
         Let .Z = RX.NO.DPT2.POST
         RX = .Z
         RXS(.PATIENT) = .Z
         Let TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT) + .Z
         Let ARRIVAL(.PATIENT) = .Y
         If ARRIVAL(.PATIENT) = 11
            DEPARTURE(.PATIENT) = 11
            Let .X = LOS49
            LOS(.PATIENT) = time.v +.X
            SCHEDULE.TIME(.PATIENT) = .X
            Call WRITE.TRACE.LINE giving "patient",
```

```
         PATIENT.ID(.PATIENT),"patient in matrix 49"
        If RXS(.PATIENT) <> 0
           TIME.INT(.PATIENT) = SCHEDULE.TIME(.PATIENT)/
                  RXS(.PATIENT)
           RX.NO.2 = RX.NO.2 + 1
           Call WRITE.TRACE.LINE giving "patient",
            PATIENT.ID(.PATIENT),"patient: RX in DPT.8140"
           Until time.v >= LOS(.PATIENT)-1
           Do
              work TIME.INT(.PATIENT) hours
              Let RX.NO.2 = RX.NO.2 + 1
           Call WRITE.TRACE.LINE giving "patient",
            PATIENT.ID(.PATIENT),"patient: RX in DPT.8140"
           Loop
        Else
           work .X hours
        Endif
        Call WRITE.TRACE.LINE giving "patient",
         PATIENT.ID(.PATIENT),"patient out matrix 49"
        Relinquish 1 DEPARTMENT(2)
        .PATIENT = .PATIENT
        BLOCK.TIME(.PATIENT) = time.v
        Call WRITE.TRACE.LINE giving "patient",
         PATIENT.ID(.PATIENT),"patient in the department
         queue 8327"
        For each DEPARTMENT
           with DPT.ID(DEPARTMENT) = 4
           Find the first case
              If found
                 File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
                 Activate a DPT.8327 now
              Endif
     Else
        DEPARTURE(.PATIENT) = 20
        Let .X = LOS50
        LOS(.PATIENT) = time.v +.X
        SCHEDULE.TIME(.PATIENT) = .X
        Call WRITE.TRACE.LINE giving "patient",
         PATIENT.ID(.PATIENT),"patient in matrix 50"
        If RXS(.PATIENT) <> 0
           TIME.INT(.PATIENT) = SCHEDULE.TIME(.PATIENT)/
                  RXS(.PATIENT)
           RX.NO.2 = RX.NO.2 + 1
           Call WRITE.TRACE.LINE giving "patient",
            PATIENT.ID(.PATIENT),"patient: RX in DPT.8140"
           Until time.v >= LOS(.PATIENT)-1
           Do
              work TIME.INT(.PATIENT) hours
              Let RX.NO.2 = RX.NO.2 + 1
              Call WRITE.TRACE.LINE giving "patient",
               PATIENT.ID(.PATIENT),"patient: RX in DPT.8140"
           Loop
        Else
           work .X hours
        Endif
```

```
                Call WRITE.TRACE.LINE giving "patient",
                 PATIENT.ID(.PATIENT),"patient out matrix 50"
                Relinquish 1 DEPARTMENT(2)
                .PATIENT = .PATIENT
                File .PATIENT in the DONE.QUEUE
                If DONE.QUEUE is not empty
                   Call PATIENT.DONE
                Endif
             Endif

          Case 12
             DEPARTURE(.PATIENT) = 20
             Let .X = LOS67
             LOS(.PATIENT) = time.v + .X
             SCHEDULE.TIME(.PATIENT) = .X
             Let .Z = RX.NO.DPT2.POST
             RX = .Z
             RXS(.PATIENT) = .Z
             Let TOTAL.RX(.PATIENT)= TOTAL.RX(.PATIENT) + .Z
             Call WRITE.TRACE.LINE giving "patient",
              PATIENT.ID(.PATIENT), "patient in matrix 67"
             If RXS(.PATIENT) <> 0
                TIME.INT(.PATIENT) = SCHEDULE.TIME(.PATIENT)/
                      RXS(.PATIENT)
                RX.NO.2 = RX.NO.2 + 1
                Call WRITE.TRACE.LINE giving "patient",
                  PATIENT.ID(.PATIENT),"patient: RX in DPT.8140"
                Until time.v >= LOS(.PATIENT)-1
                Do
                   work TIME.INT(.PATIENT) hours
                   Let RX.NO.2 = RX.NO.2 + 1
                   Call WRITE.TRACE.LINE giving "patient",
                    PATIENT.ID(.PATIENT),"patient: RX in DPT.8140"
                Loop
             Else
                work .X hours
             Endif
             Call WRITE.TRACE.LINE giving "patient",
              PATIENT.ID(.PATIENT), "patient out matrix 67"
             Relinquish 1 DEPARTMENT(2)
             .PATIENT = .PATIENT
             File .PATIENT in the DONE.QUEUE
             If DONE.QUEUE is not empty
                Call PATIENT.DONE
             Endif
          Endselect
       Endif
    Endif
End
```

```
''****************
Process DPT.8327
''***************

Define .PATIENT as a pointer variable
Define .X, .Y as real variables

For each DEPARTMENT
with DPT.ID(DEPARTMENT) = 4
Find the first case
If found
   If DEPARTMENT.QUEUE(DEPARTMENT) is not empty
      Remove first .PATIENT from DEPARTMENT.QUEUE(DEPARTMENT)
      Request 1 DEPARTMENT(4)
      TRANSFER = TRANSFER + 1
      If time.v - BLOCK.TIME(.PATIENT) > 0.1
         Call WRITE.TRACE.LINE giving "patient", PATIENT.ID(.PATIENT)
         "patient is registered as blocked"
         BLOCK.TEL = BLOCK.TEL + 1
         BLOCKTIME = ((time.v - BLOCK.TIME(.PATIENT))/
                (time.v - ARRIVAL.TIME(.PATIENT))) * 100
      Endif
      Call WRITE.TRACE.LINE giving "patient", PATIENT.ID(.PATIENT),
       "patient in department 8327"
      PRE.RX = TOTAL.RX(.PATIENT)
      TOTAL.RX(.PATIENT) = 0
      If OK.TEST(.PATIENT) = 0
         PRE.LOS(.PATIENT) = time.v - ARRIVAL.TIME(.PATIENT)
         PRE.LENGTH = PRE.LOS(.PATIENT)
         If time.v > (WARMUP.PERIOD + RESET.TIME) * 24
            If P1 = 1
               If DRG(.PATIENT) = 107
                   Remove .PATIENT from the LIST.OF.PATIENTS
                   MPS.CHANGE(.PATIENT) = AVGLOS.PRE.107
                          - Int.f(PRE.LOS(.PATIENT)/24)
               Else
                   Remove .PATIENT from the LIST.OF.PATIENTS
                   MPS.CHANGE(.PATIENT) = AVGLOS.PRE.104
                         - Int.f(PRE.LOS(.PATIENT)/24)
               Endif
               File .PATIENT in the LIST.OF.PATIENTS
               If MPS.CHANGE(.PATIENT) <> 0
                  Call WRITE.TRACE.LINE giving "patient",
                   PATIENT.ID(.PATIENT),"MPS is to be changed"
                  Call CHANGE.MPS giving PATIENT.ID(.PATIENT)
               Endif
            Endif
         Endif
      Endif
      Select case DEPARTURE(.PATIENT)

      Case 4
          Let .Y = MTR.8327C
          Let ARRIVAL(.PATIENT) = .Y
          If ARRIVAL(.PATIENT) = 6
```

```
      DEPARTURE(.PATIENT) = 6
      If P4=1
         let .X = NORMAL.F(58.2,56.46*P5,3)
         If .X <= 13
            Let .X = 45
         Endif
      Else
         Let .X = LOS15
      Endif
      SCHEDULE.TIME(.PATIENT) = .X
      If OK.TEST(.PATIENT) = 0
         SURG.LOS(.PATIENT) = SCHEDULE.TIME(.PATIENT)
         SURG.LENGTH = SCHEDULE.TIME(.PATIENT)
         SURG.RX = (SURG.LENGTH/24) * SI.RX4
         RX.NO.83 = RX.NO.83 + ((SURG.RX*24)/SURG.LENGTH)
         Call WRITE.TRACE.LINE giving "patient",
          PATIENT.ID(.PATIENT), "Rx for patient in 8327"
         OK.TEST(.PATIENT) = 1
      Else
         TIME.INT(.PATIENT) = SI.RX4
         TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT)+
         (TIME.INT(.PATIENT)*(SCHEDULE.TIME(.PATIENT)/24))
         RX.NO.83 = RX.NO.83 + TIME.INT(.PATIENT)
         Call WRITE.TRACE.LINE giving "patient",
          PATIENT.ID(.PATIENT), "Rx for patient in 8327"
      Endif
      Call WRITE.TRACE.LINE giving "patient",
       PATIENT.ID(.PATIENT), "patient in matrix 15"
      Work .X hours
      Call WRITE.TRACE.LINE giving "patient",
       PATIENT.ID(.PATIENT), "patient out matrix 15"
      Relinquish 1 DEPARTMENT(4)
      ARRIVAL.TIME(.PATIENT) = time.v
      .PATIENT = .PATIENT
      For each DEPARTMENT
         with DPT.ID(DEPARTMENT) = 2
         Find the first case
         If found
            File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
         Endif
         Activate a DPT.8140 now
   Else
      If ARRIVAL(.PATIENT) = 7
         DEPARTURE(.PATIENT) = 7
         Let .X = LOS16
         SCHEDULE.TIME(.PATIENT) = .X
         If OK.TEST(.PATIENT) = 0
            SURG.LOS(.PATIENT) = SCHEDULE.TIME(.PATIENT)
            SURG.LENGTH = SCHEDULE.TIME(.PATIENT)
            SURG.RX = (SURG.LENGTH/24) * SI.RX4
            RX.NO.83 = RX.NO.83 + ((SURG.RX*24)/SURG.LENGTH)
            Call WRITE.TRACE.LINE giving "patient",
             PATIENT.ID(.PATIENT), "Rx for patient in 8327"
            OK.TEST(.PATIENT) = 1
         Else
```

```
        TIME.INT(.PATIENT) = SI.RX4
        TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT)+
        (TIME.INT(.PATIENT)*(SCHEDULE.TIME(.PATIENT)/24))
        RX.NO.83 = RX.NO.83 + TIME.INT(.PATIENT)
        Call WRITE.TRACE.LINE giving "patient",
         PATIENT.ID(.PATIENT), "Rx for patient in 8327"
     Endif
     Call WRITE.TRACE.LINE giving "patient",
      PATIENT.ID(.PATIENT), "patient in matrix 16"
     Work .X hours
     Call WRITE.TRACE.LINE giving "patient",
      PATIENT.ID(.PATIENT), "patient out matrix 16"
     Relinquish 1 DEPARTMENT(4)
     ARRIVAL.TIME(.PATIENT) = time.v
     .PATIENT = .PATIENT
     For each DEPARTMENT
        with DPT.ID(DEPARTMENT) = 3
        Find the first case
        If found
           File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
        Endif
        Activate a DPT.8325 now
  Else
     DEPARTURE(.PATIENT) = 20
     Let .X = LOS17
     SCHEDULE.TIME(.PATIENT) = .X
     If OK.TEST(.PATIENT) = 0
        SURG.LOS(.PATIENT) = SCHEDULE.TIME(.PATIENT)
        SURG.LENGTH = SCHEDULE.TIME(.PATIENT)
        SURG.RX = (SURG.LENGTH/24) * SI.RX4
        RX.NO.83 = RX.NO.83 + ((SURG.RX*24)/SURG.LENGTH)
        Call WRITE.TRACE.LINE giving "patient",
         PATIENT.ID(.PATIENT), "Rx for patient in 8327"
        OK.TEST(.PATIENT) = 1
     Else
        TIME.INT(.PATIENT) = SI.RX4
        TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT)+
        (TIME.INT(.PATIENT)*(SCHEDULE.TIME(.PATIENT)/24))
        RX.NO.83 = RX.NO.83 + TIME.INT(.PATIENT)
        Call WRITE.TRACE.LINE giving "patient",
        PATIENT.ID(.PATIENT), "Rx for patient in 8327"
     Endif
     Call WRITE.TRACE.LINE giving "patient",
      PATIENT.ID(.PATIENT), "patient in matrix 17"
     Work .X hours
     Call WRITE.TRACE.LINE giving "patient",
      PATIENT.ID(.PATIENT), "patient out matrix 17"
     Relinquish 1 DEPARTMENT(4)
     ARRIVAL.TIME(.PATIENT) = time.v
    .PATIENT = .PATIENT
   File .PATIENT in the DONE.QUEUE
   If DONE.QUEUE is not empty
      Call PATIENT.DONE
   Endif
Endif
```

```
         Endif

      Case 8
         Let .Y = MTR.8327C2
         Let ARRIVAL(.PATIENT) = .Y
         If ARRIVAL(.PATIENT) = 9
            DEPARTURE(.PATIENT) = 9
            Let .X = LOS42
            SCHEDULE.TIME(.PATIENT) = .X
            If OK.TEST(.PATIENT) = 0
               SURG.LOS(.PATIENT) = SCHEDULE.TIME(.PATIENT)
               SURG.LENGTH = SCHEDULE.TIME(.PATIENT)
               SURG.RX = (SURG.LENGTH/24) * SI.RX4
               RX.NO.83 = RX.NO.83 + ((SURG.RX*24)/SURG.LENGTH)
               Call WRITE.TRACE.LINE giving "patient",
                PATIENT.ID(.PATIENT), "Rx for patient in 8327"
               OK.TEST(.PATIENT) = 1
            Else
               TIME.INT(.PATIENT) = SI.RX4
               TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT)+
               (TIME.INT(.PATIENT)*(SCHEDULE.TIME(.PATIENT)/24))
               RX.NO.83 = RX.NO.83 + TIME.INT(.PATIENT)
               Call WRITE.TRACE.LINE giving "patient",
               PATIENT.ID(.PATIENT), "Rx for patient in 8327"
            Endif
            Call WRITE.TRACE.LINE giving "patient",
             PATIENT.ID(.PATIENT), "patient in matrix 42"
            Work .X hours
            Call WRITE.TRACE.LINE giving "patient",
             PATIENT.ID(.PATIENT), "patient out matrix 42"
            Relinquish 1 DEPARTMENT(4)
            ARRIVAL.TIME(.PATIENT) = time.v
           .PATIENT = .PATIENT
           For each DEPARTMENT
           with DPT.ID(DEPARTMENT) = 2
           Find the first case
           If found
              File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
           Endif
           Activate a DPT.8140 now
        Else
           DEPARTURE(.PATIENT) = 20
           Let .X = LOS44
           SCHEDULE.TIME(.PATIENT) = .X
           If OK.TEST(.PATIENT) = 0
              SURG.LOS(.PATIENT) = SCHEDULE.TIME(.PATIENT)
              SURG.LENGTH = SCHEDULE.TIME(.PATIENT)
              SURG.RX = (SURG.LENGTH/24) * SI.RX4
              RX.NO.83 = RX.NO.83 + ((SURG.RX*24)/SURG.LENGTH)
              Call WRITE.TRACE.LINE giving "patient",
              PATIENT.ID(.PATIENT), "Rx for patient in 8327"
              OK.TEST(.PATIENT) = 1
           Else
              TIME.INT(.PATIENT) = SI.RX4
              TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT)+
```

```
         (TIME.INT(.PATIENT)*(SCHEDULE.TIME(.PATIENT)/24))
         RX.NO.83 = RX.NO.83 + TIME.INT(.PATIENT)
         Call WRITE.TRACE.LINE giving "patient",
         PATIENT.ID(.PATIENT), "Rx for patient in 8327"
      Endif
      Call WRITE.TRACE.LINE giving "patient",
      PATIENT.ID(.PATIENT), "patient in matrix 44"
      Work .X hours
      Call WRITE.TRACE.LINE giving "patient",
      PATIENT.ID(.PATIENT), "patient out matrix 44"
      Relinquish 1 DEPARTMENT(4)
      ARRIVAL.TIME(.PATIENT) = time.v
      .PATIENT = .PATIENT
      File .PATIENT in the DONE.QUEUE
      If DONE.QUEUE is not empty
         Call PATIENT.DONE
      Endif
   Endif
Case 11
   Let .Y = MTR.8327C3
   Let ARRIVAL(.PATIENT) = .Y
   If ARRIVAL(.PATIENT) = 12
      DEPARTURE(.PATIENT) = 12
      Let .X = LOS60
      SCHEDULE.TIME(.PATIENT) = .X
      If OK.TEST(.PATIENT) = 0
         SURG.LOS(.PATIENT) = SCHEDULE.TIME(.PATIENT)
         SURG.LENGTH = SCHEDULE.TIME(.PATIENT)
         SURG.RX = (SURG.LENGTH/24) * SI.RX4
         RX.NO.83 = RX.NO.83 + ((SURG.RX*24)/SURG.LENGTH)
         Call WRITE.TRACE.LINE giving "patient",
          PATIENT.ID(.PATIENT), "Rx for patient in 8327"
         OK.TEST(.PATIENT) = 1
      Else
         TIME.INT(.PATIENT) = SI.RX4
         TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT)+
         (TIME.INT(.PATIENT)*(SCHEDULE.TIME(.PATIENT)/24))
         RX.NO.83 = RX.NO.83 + TIME.INT(.PATIENT)
         Call WRITE.TRACE.LINE giving "patient",
         PATIENT.ID(.PATIENT), "Rx for patient in 8327"
      Endif
      Call WRITE.TRACE.LINE giving "patient",
       PATIENT.ID(.PATIENT), "patient in matrix 60"
      Work .X hours
      Call WRITE.TRACE.LINE giving "patient",
       PATIENT.ID(.PATIENT), "patient out matrix 60"
      Relinquish 1 DEPARTMENT(4)
      ARRIVAL.TIME(.PATIENT) = time.v
      .PATIENT = .PATIENT
      For each DEPARTMENT
         with DPT.ID(DEPARTMENT) = 2
         Find the first case
         If found
            File .PATIENT in DEPARTMENT.QUEUE(DEPARTMENT)
         Endif
```

```
              Activate a DPT.8140 now
        Else
           DEPARTURE(.PATIENT) = 20
           Let .X = LOS62
           SCHEDULE.TIME(.PATIENT) = .X
           If OK.TEST(.PATIENT) = 0
              SURG.LOS(.PATIENT) = SCHEDULE.TIME(.PATIENT)
              SURG.LENGTH = SCHEDULE.TIME(.PATIENT)
              SURG.RX = (SURG.LENGTH/24) * SI.RX4
              RX.NO.83 = RX.NO.83 + ((SURG.RX*24)/SURG.LENGTH)
              Call WRITE.TRACE.LINE giving "patient",
               PATIENT.ID(.PATIENT), "Rx for patient in 8327"
              OK.TEST(.PATIENT) = 1
           Else
              TIME.INT(.PATIENT) = SI.RX4
              TOTAL.RX(.PATIENT) = TOTAL.RX(.PATIENT)+
              (TIME.INT(.PATIENT)*(SCHEDULE.TIME(.PATIENT)/24))
              RX.NO.83 = RX.NO.83 + TIME.INT(.PATIENT)
              Call WRITE.TRACE.LINE giving "patient",
               PATIENT.ID(.PATIENT), "Rx for patient in 8327"
           Endif
           Call WRITE.TRACE.LINE giving "patient",
            PATIENT.ID(.PATIENT), "patient in matrix 62"
           Work .X hours
           Call WRITE.TRACE.LINE giving "patient",
            PATIENT.ID(.PATIENT), "patient out matrix 62"
           Relinquish 1 DEPARTMENT(4)
           ARRIVAL.TIME(.PATIENT) = time.v
           .PATIENT = .PATIENT
           File .PATIENT in the DONE.QUEUE
           If DONE.QUEUE is not empty
              Call PATIENT.DONE
           Endif
        Endif
      Endselect
   Endif
Endif
End
```

```
''********************
Routine PATIENT.DONE
''********************

    Define .TIME as a real variable
    Define .PATIENT as pointer variable
    Define .PAT as a pointer variable

    Remove the first .PATIENT from the DONE.QUEUE
    For each .PAT in the LIST.OF.PATIENTS
       with PATIENT.ID(.PAT) = PATIENT.ID(.PATIENT)
       Find the first case
       If found
          Remove .PAT from the LIST.OF.PATIENTS
       Endif
    .TIME = time.v
    POST.LOS(.PATIENT) = .TIME - ARRIVAL.TIME(.PATIENT)
    POST.LENGTH = POST.LOS(.PATIENT)
    LENGTH.OF.STAY = PRE.LOS(.PATIENT)+POST.LOS(.PATIENT)+SURG.LOS(.PA
    POST.RX = TOTAL.RX(.PATIENT)
    Select case DRG(.PATIENT)

       Case 104
          PRE.LOS.104 = PRE.LOS(.PATIENT)
          POST.LOS.104 = POST.LOS(.PATIENT)
          SURG.LOS.104 = SURG.LOS(.PATIENT)
          TOTAL.LOS.104 = PRE.LOS.104 + POST.LOS.104 + SURG.LOS.104
          If time.v >= (WARMUP.PERIOD+RESET.TIME+START.STAT)*24
             If DISCHARGE.TIME(.PATIENT) <= INT.f(.TIME/24)
                LATENESS.TIME = Int.f(.TIME/24) -
                    DISCHARGE.TIME(.PATIENT)
             Else
                LATENESS.TIME = DISCHARGE.TIME(.PATIENT) -
                    int.f(.TIME/24)
             Endif
             LAT.COUNT = LAT.COUNT + 1
             If DISCHARGE.TIME.RE(.PATIENT) <= INT.f(.TIME/24)
                CURRENT.LATENESS = Int.f(.TIME/24)
                    - DISCHARGE.TIME.RE(.PATIENT)
                SQUARE.CURLAT = (CURRENT.LATENESS)**2
             Else
                CURRENT.LATENESS = DISCHARGE.TIME.RE(.PATIENT) -
                    Int.f(.TIME/24)
                SQUARE.CURLAT = (CURRENT.LATENESS)**2
             Endif
          Endif

       Case 107
          PRE.LOS.107 = PRE.LOS(.PATIENT)
          POST.LOS.107 = POST.LOS(.PATIENT)
          SURG.LOS.107 = SURG.LOS(.PATIENT)
          TOTAL.LOS.107 = PRE.LOS.107 + POST.LOS.107 + SURG.LOS.107
          If time.v >= (WARMUP.PERIOD+RESET.TIME+START.STAT)*24
             If DISCHARGE.TIME(.PATIENT) <= INT.f(.TIME/24)
                LATENESS.TIME = Int.f(.TIME/24) -
```

```
                    DISCHARGE.TIME(.PATIENT)
               Else
                  LATENESS.TIME = DISCHARGE.TIME(.PATIENT) -
                      Int.f(.TIME/24)
               Endif
                  LAT.COUNT = LAT.COUNT + 1
               If DISCHARGE.TIME.RE(.PATIENT) <= INT.f(.TIME/24)
                  CURRENT.LATENESS = Int.f(.TIME/24) -
                      DISCHARGE.TIME.RE(.PATIENT)
                  SQUARE.CURLAT = (CURRENT.LATENESS)**2
               Else
                  CURRENT.LATENESS = DISCHARGE.TIME.RE(.PATIENT) -
                      Int.f(.TIME/24)
                  SQUARE.CURLAT = (CURRENT.LATENESS)**2
              Endif
           Endif
    Endselect
    LATE.NUMBER = LATE.NUMBER + 1
    Call WRITE.TRACE.LINE giving "patient", PATIENT.ID(.PATIENT),
     "patient is leaving the hospital"
    DISCHARGE.NUMBER = DISCHARGE.NUMBER + 1
    Destroy the PATIENT called .PATIENT
End
```

```
''*********************
Process GENERATE.MPS
''*******************

Define .COUNT as an integer variable
Define .DAY as pointer variable



.COUNT = WARMUP.PERIOD + RESET.TIME + START.STAT + (RESET.INTERVAL)

For I = 1 to RUN.LENGTH + (1* RESET.INTERVAL)
Do
   Create a DAY called .DAY
   Add 1 to DAY.COUNTER
   DAY.NUMBER(.DAY) = DAY.COUNTER
   File .DAY in MPS.DRG104
   File .DAY in MPS.DRG107
loop

COUNT = .COUNT

End
```

```
''****************************
Process Generate.Departments
''****************************

Define I as an integer variable

I = 1
N.DEPARTMENT = NUMBER.OF.DEPARTMENTS
Create every DEPARTMENT
For each DEPARTMENT,
Do
  If I <> 4
     U.DEPARTMENT(DEPARTMENT) = 40
  Else
    If P2 = 1
       U.DEPARTMENT(DEPARTMENT) = ICU.BEDS
    Else
       U.DEPARTMENT(DEPARTMENT) = 40
    Endif
 Endif
 DPT.ID(DEPARTMENT) = I
 add 1 to I
Loop

End
```

```
''*************************
Process RESET.STATISTICS
''*************************

Define .HLP3 as a text variable

Wait (WARMUP.PERIOD*24) hours
Call WRITE.RESULT
Wait (RESET.TIME*24) hours
  AVGLOS.PRE.104 = Int.f((AVG.PRE.LOS.104 + (P6*DEV.PRE.LOS.104))/24)
  AVGLOS.ADM.104 = Int.f((AVG.PRE.LOS.104)/24)
  AVGLOS.POST.104 = Int.f((AVG.POST.LOS.104 + (P6*DEV.POST.LOS.104))/
  AVGLOS.SURG.104 = Int.f((AVG.SURG.LOS.104 + (P6*DEV.SURG.LOS.104))/
  AVGLOS.PRE.105 = Int.f((AVG.PRE.LOS.105 + (P6*DEV.PRE.LOS.105))/24)
  AVGLOS.POST.105 = Int.f((AVG.POST.LOS.105 + (P6*DEV.POST.LOS.105))/
  AVGLOS.SURG.105 = Int.f((AVG.SURG.LOS.105 + (P6*DEV.SURG.LOS.105))/
  AVGLOS.PRE.106 = Int.f((AVG.PRE.LOS.106 + (P6*DEV.PRE.LOS.106))/24)
  AVGLOS.POST.106 = Int.f((AVG.POST.LOS.106 + (P6*DEV.POST.LOS.106))/
  AVGLOS.SURG.106 = Int.f((AVG.SURG.LOS.106 + (P6*DEV.SURG.LOS.106))/
  AVGLOS.PRE.107 = Int.f((AVG.PRE.LOS.107 + (P6*DEV.PRE.LOS.107))/24)
  AVGLOS.ADM.107 = Int.f((AVG.PRE.LOS.107)/24)
  AVGLOS.POST.107 = Int.f((AVG.POST.LOS.107 + (P6*DEV.POST.LOS.107))/
  AVGLOS.SURG.107 = Int.f((AVG.SURG.LOS.107 + (P6*DEV.SURG.LOS.107))/
  AVGLOS.TOTAL.104 = AVGLOS.PRE.104 + AVGLOS.POST.104 + AVGLOS.SURG.1
  AVGLOS.TOTAL.105 = AVGLOS.PRE.105 + AVGLOS.POST.105 + AVGLOS.SURG.1
  AVGLOS.TOTAL.106 = AVGLOS.PRE.106 + AVGLOS.POST.106 + AVGLOS.SURG.1
  AVGLOS.TOTAL.107 = AVGLOS.PRE.107 + AVGLOS.POST.107 + AVGLOS.SURG.1
  AVG.RX.PRE = (AVG.PRE.RX/AVG.PRE.LOS) * 24
  AVG.RX.POST = (AVG.POST.RX/AVG.POST.LOS) * 24
  AVG.RX.SURG = (AVG.SURG.RX/AVG.SURG.LOS) * 24
  LATENESS.TIME = 0
Call WRITE.RESULT
Wait (START.STAT * 24) hours
Call WRITE.RESULT
Until time.v >= (RUN.LENGTH*24)
do
   Wait (RESET.INTERVAL*24) hours
   Call WRITE.RESULTS.1
   Call WRITE.RESULTS.2
   call WRITE.RESULT
loop
Use unit 45 for output

Print 10 lines with SEED.V(1), SEED.V(2), SEED.V(3), SEED.V(4), SEED.
    SEED.V(6), SEED.V(7), SEED.V(8), SEED.V(9), SEED.V(10) thus
    *************
    *************
    *************
    *************
    *************
    *************
    *************
    *************
    *************
    *************
```

```
DESIGN = DESIGN + 1

Select Case DESIGN
    Case 66
        P1 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0
    Case 67
        P1 = 0
        P2 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0
    Case 68
        P1 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0
    Case 69
        P1 = 0
        P2 = 0
        P5 = 1.25
        HELP.1PGE = 0
        HELP.2PGE = 0
    Case 70
        P1 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0
    Case 71
        P1 = 0
        P2 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0
    Case 72
        P1 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0
    Case 73
        P1 = 0
        P2 = 0
        P5 = 1
        P6 = 0.25
        HELP.1PGE = 0
        HELP.2PGE = 0
    Case 74
        P1 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0
    Case 75
        P1 = 0
        P2 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0
    Case 76
        P1 = 1
        HELP.1PGE = 0
```

```
            HELP.2PGE = 0
        Case 77
            P1 = 0
            P2 = 0
            P5 = 1.25
            HELP.1PGE = 0
            HELP.2PGE = 0
        Case 78
            P1 = 1
            HELP.1PGE = 0
            HELP.2PGE = 0
        Case 79
            P1 = 0
            P2 = 1
            HELP.1PGE = 0
            HELP.2PGE = 0
        Case 80
            P1 = 1
            HELP.1PGE = 0
            HELP.2PGE = 0
        Case 81
            P1 = 0
            P2 = 0
            P5 = 1
            P6 = 0
            HELP.1PGE = 0.25
            HELP.2PGE = 0
        Case 82
            P1 = 1
            HELP.1PGE = 0
            HELP.2PGE = 0
        Case 83
            P1 = 0
            P2 = 1
            HELP.1PGE = 0.25
            HELP.2PGE = 0
        Case 84
            P1 = 1
            HELP.1PGE = 0.25
            HELP.2PGE = 0
        Case 85
            P1 = 0
            P2 = 0
            P5 = 1.25
            HELP.1PGE = 0.25
            HELP.2PGE = 0
        Case 86
            P1 = 1
            HELP.1PGE = 0.25
            HELP.2PGE = 0
        Case 87
            P1 = 0
            P2 = 1
            HELP.1PGE = 0.25
            HELP.2PGE = 0
```

```
Case 88
    P1 = 1
    HELP.1PGE = 0
    HELP.2PGE = 0
Case 89
    P1 = 0
    P2 = 0
    P5 = 1
    P6 = 0.25
    HELP.1PGE = 0.25
    HELP.2PGE = 0
Case 90
    P1 = 1
    HELP.1PGE = 0.25
    HELP.2PGE = 0
Case 91
    P1 = 0
    P2 = 1
    HELP.1PGE = 0.25
    HELP.2PGE = 0
Case 92
    P1 = 1
    HELP.1PGE = 0.25
    HELP.2PGE = 0
Case 93
    P1 = 0
    P2 = 0
    P5 = 1.25
    HELP.1PGE = 0.25
    HELP.2PGE = 0
Case 94
    P1 = 1
    HELP.1PGE = 0.25
    HELP.2PGE = 0
Case 95
    P1 = 0
    P2 = 1
    HELP.1PGE = 0.25
    HELP.2PGE = 0
Case 96
    P1 = 1
    HELP.1PGE = 0.25
    HELP.2PGE = 0
Case 97
    P1 = 0
    P2 = 0
    P5 = 1
    P6 = 0
    HELP.1PGE = 0
    HELP.2PGE = 0.25
Case 98
    P1 = 1
    HELP.1PGE = 0
    HELP.2PGE = 0.25
Case 99
```

```
        P1 = 0
        P2 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0.25
    Case 100
        P1 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0.25
    Case 101
        P1 = 0
        P2 = 0
        P5 = 1.25
        HELP.1PGE = 0
        HELP.2PGE = 0.25
    Case 102
        P1 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0.25
    Case 103
        P1 = 0
        P2 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0.25
    Case 104
        P1 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0.25
    Case 105
        P1 = 0
        P2 = 0
        P5 = 1
        P6 = 0.25
        HELP.1PGE = 0
        HELP.2PGE = 0.25
    Case 106
        P1 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0.25
    Case 107
        P1 = 0
        P2 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0.25
    Case 108
        P1 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0.25
    Case 109
        P1 = 0
        P2 = 0
        P5 = 1.25
        HELP.1PGE = 0
        HELP.2PGE = 0.25
    Case 110
        P1 = 1
```

```
        HELP.1PGE = 0
        HELP.2PGE = 0.25
    Case 111
        P1 = 0
        P2 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0.25
    Case 112
        P1 = 1
        HELP.1PGE = 0
        HELP.2PGE = 0.25
    Case 113
        P1 = 0
        P2 = 0
        P5 = 1
        P6 = 0
        HELP.1PGE = 0.25
        HELP.2PGE = 0.25
    Case 114
        P1 = 1
        HELP.1PGE = 0.25
        HELP.2PGE = 0.25
    Case 115
        P1 = 0
        P2 = 1
        HELP.1PGE = 0.25
        HELP.2PGE = 0.25
    Case 116
        P1 = 1
        HELP.1PGE = 0.25
        HELP.2PGE = 0.25
    Case 117
        P1 = 0
        P2 = 0
        P5 = 1.25
        HELP.1PGE = 0.25
        HELP.2PGE = 0.25
    Case 118
        P1 = 1
        HELP.1PGE = 0.25
        HELP.2PGE = 0.25
    Case 119
        P1 = 0
        P2 = 1
        HELP.1PGE = 0.25
        HELP.2PGE = 0.25
    Case 120
        P1 = 1
        HELP.1PGE = 0.25
        HELP.2PGE = 0.25
    Case 121
        P1 = 0
        P2 = 0
        P5 = 1
        P6 = 0.25
```

```
            HELP.1PGE = 0.25
            HELP.2PGE = 0.25
        Case 122
            P1 = 1
            HELP.1PGE = 0.25
            HELP.2PGE = 0.25
        Case 123
            P1 = 0
            P2 = 1
            HELP.1PGE = 0.25
            HELP.2PGE = 0.25
        Case 124
            P1 = 1
            HELP.1PGE = 0.25
            HELP.2PGE = 0.25
        Case 125
            P1 = 0
            P2 = 0
            P5 = 1.25
            HELP.1PGE = 0.25
            HELP.2PGE = 0.25
        Case 126
            P1 = 1
            HELP.1PGE = 0.25
            HELP.2PGE = 0.25
        Case 127
            P1 = 0
            P2 = 1
            HELP.1PGE = 0.25
            HELP.2PGE = 0.25
        Case 128
            P1 = 1
            HELP.1PGE = 0.25
            HELP.2PGE = 0.25
        Case 129
            P1 = 0
            HELP.1PGE = 0.25
            HELP.2PGE = 0.25
    Endselect
    .HLP3 = "*"

    Use unit 42 for output

    Print 10 lines with PLANNING.PERIODICITY, HELP.1PGE,
        .HLP3, HELP.2PGE, .HLP3,
         P1, P2, P3, P5, P6, NUMBER.FOR.OR, DESIGN thus
**
*.** 0 1 1   *
*.** 0 1 1   *
*
*
*
*.**
*.**
*
```

```
****

Use unit 6 for output

end
```

```
''*******************
Routine MPS.DRG.107
''*******************

Define .MPS.NUMBER, .DAY.NUMBER, .DAY.NUMBER.X, .SIGN
     and .X as integer variables

Define .DAY, .DAYS, .FDAY, .DAYS1, .FDAYS1 as pointer variables

TIME.PARAMETER = time.v

For each .DAY in the MPS.DRG107
    with DAY.NUMBER(.DAY) = Int.f(TIME.PARAMETER/24)
    Find the first case
    If found,
       Remove the .DAY from the MPS.DRG107
       .DAYS1 = .DAY
       File .DAY in the MPS.DRG107
    Endif
For each .DAY in the MPS.DRG107
    with DAY.NUMBER(.DAY) = Int.f((TIME.PARAMETER/24)+PLANNING.HORIZO
    Find the first case
    If found,
       Remove the .DAY from the MPS.DRG107
       .FDAYS1 = .DAY
       File .DAY in the MPS.DRG107
    Endif

For each .DAY from .DAYS1 in MPS.DRG107 until .DAY = .FDAYS1
Do
   Remove .DAY from the MPS.DRG107
   .MPS.NUMBER = NO.OF.DISCHARGES(.DAY) - PRE.NO.OF.DISCHARGES(.DAY)
   If .MPS.NUMBER <> 0
      MPS.NUMBER = NO.OF.DISCHARGES(.DAY)
      NUMBER.OF.DISCHARGES = NUMBER1.OF.DISCHARGES +
            NO.OF.DISCHARGES(.DAY)
     .DAY.NUMBER = DAY.NUMBER(.DAY)
     .DAYS = .DAY
     File .DAY in the MPS.DRG107
     If P1 = 0
       .DAY.NUMBER.X = .DAY.NUMBER - (Int.f(AVGLOS.PRE.107+
            AVGLOS.POST.107+AVGLOS.SURG.107))
       If .DAY.NUMBER.X >= Int.f(TIME.PARAMETER/24)
               - (PLANNING.PERIODICITY +1)
          For each .DAY in the MPS.DRG107
             with DAY.NUMBER(.DAY) = .DAY.NUMBER.X
             Find the first case
             If found
                Remove .DAY from the MPS.DRG107
                If (.DAY.NUMBER-Int.f(AVGLOS.PRE.107+AVGLOS.POST.107+
                      AVGLOS.SURG.107))> Int.f(TIME.PARAMETER/24)
                   .FDAY = .DAY
                   File .DAY in the MPS.DRG107
                Else
                   .FDAY = Int.f(TIME.PARAMETER/24)
```

```
                 File .DAY in the MPS.DRG107
              Endif
           Endif
      Else
           .SIGN = 1
        Endif
   Else
      .DAY.NUMBER.X = .DAY.NUMBER - (Int.f(AVGLOS.PRE.107+
              AVGLOS.POST.107+AVGLOS.SURG.107))
      If .DAY.NUMBER.X >= Int.f(TIME.PARAMETER/24) -
              (PLANNING.PERIODICITY +
         Int.f(AVGLOS.PRE.107))
         For each .DAY in the MPS.DRG107
            with DAY.NUMBER(.DAY) = .DAY.NUMBER.X
            Find the first case
            If found
               Remove .DAY from the MPS.DRG107
               If (.DAY.NUMBER-Int.f(AVGLOS.PRE.107+AVGLOS.POST.107
                      AVGLOS.SURG.107))> Int.f(TIME.PARAMETER/24)
                  .FDAY = .DAY
                  File .DAY in the MPS.DRG107
               Else
                  .FDAY = Int.f(TIME.PARAMETER/24)
                  File .DAY in the MPS.DRG107
               Endif
            Endif
      Else
        .SIGN = 1
      Endif
   Endif

If .SIGN <> 1
   For each .DAY from .DAYS in MPS.DRG107 in reverse order until
   .DAY = .FDAY
   Do
      Remove .DAY from the MPS.DRG107
      If .DAY.NUMBER <= AVGLOS.POST.107
              .X = NO.POST.OPERATIVE(.DAY)
         NO.POST.OPERATIVE(.DAY)= .X + .MPS.NUMBER
         PRE.NO.OF.DISCHARGES(.DAY) = NO.OF.DISCHARGES(.DAY)
         Call WRITE.TRACE.MPS giving "DAY", DAY.NUMBER(.DAY),
          NO.POST.OPERATIVE(.DAY), "postop 107"
      Else
         If DAY.NUMBER(.DAY) >= 1  and
                 DAY.NUMBER(.DAY) > (.DAY.NUMBER - AVGLOS.POST.107)
            .X = NO.POST.OPERATIVE(.DAY)
            NO.POST.OPERATIVE(.DAY)= .X + .MPS.NUMBER
            PRE.NO.OF.DISCHARGES(.DAY) = NO.OF.DISCHARGES(.DAY)
            Call WRITE.TRACE.MPS giving "DAY", DAY.NUMBER(.DAY),
             NO.POST.OPERATIVE(.DAY), "postop 107"
         Else
            If DAY.NUMBER(.DAY) >= 1 and DAY.NUMBER(.DAY)
                > (.DAY.NUMBER - (AVGLOS.POST.107+AVGLOS.SURG.107))
                and DAY.NUMBER(.DAY) <= (.DAY.NUMBER - AVGLOS.POST.
              .X = NO.SURGICAL(.DAY)
```

```
                NO.SURGICAL(.DAY) = .X + .MPS.NUMBER
                PRE.NO.OF.DISCHARGES(.DAY) = NO.OF.DISCHARGES(.DAY)
                Call WRITE.TRACE.MPS giving "DAY", DAY.NUMBER(.DAY),
                 NO.SURGICAL(.DAY), "surg 107"
             Else
                If DAY.NUMBER(.DAY) >= 1 and DAY.NUMBER(.DAY) <=
                      (.DAY.NUMBER - AVGLOS.POST.107 - AVGLOS.SURG.10
                   .X = NO.PRE.OPERATIVE(.DAY)
                   NO.PRE.OPERATIVE(.DAY) = .X + .MPS.NUMBER
                   PRE.NO.OF.DISCHARGES(.DAY) = NO.OF.DISCHARGES(.DAY
                   Call WRITE.TRACE.MPS giving "DAY", DAY.NUMBER(.DAY
                    NO.PRE.OPERATIVE(.DAY), "preop 107"
                Endif
             Endif
           Endif
        Endif
        PLAN.RX.FOR.DAY(.DAY) = (NO.POST.OPERATIVE(.DAY) * AVG.RX.POS
             + (NO.SURGICAL(.DAY) * AVG.RX.SURG) +
            (NO.PRE.OPERATIVE(.DAY) * AVG.RX.PRE)
        PLAN.BED.FOR.DAY(.DAY) = NO.PRE.OPERATIVE(.DAY) +
            NO.SURGICAL(.DAY) + NO.POST.OPERATIVE(.DAY)
        File .DAY in the MPS.DRG107
     Loop
     .DAY = .DAYS
  Else
     .SIGN = 0
  Endif
  Else
     File .DAY in the MPS.DRG107
  Endif
loop
Call WRITE.MPS.RESULTS
End
```

```
''********************
ROUTINE MPS.DRG.104
''********************

Define .MPS.NUMBER, .DAY.NUMBER, .DAY.NUMBER.X, .X and .SIGN
     as integer variables
Define .DAY, .DAYS, .FDAY, .DAYS1, .FDAYS1 as pointer variables

TIME.PARAMETER = time.v

For each .DAY in the MPS.DRG104
   with DAY.NUMBER(.DAY) = Int.f(TIME.PARAMETER/24)
   Find the first case
   If found,
      Remove the .DAY from the MPS.DRG104
      .DAYS1 = .DAY
      File .DAY in the MPS.DRG104
   Endif
For each .DAY in the MPS.DRG104
   with DAY.NUMBER(.DAY) = Int.f(TIME.PARAMETER/24) + PLANNING.HORIZON
   Find the first case
   If found,
      Remove the .DAY from the MPS.DRG104
      .FDAYS1 = .DAY
      File .DAY in the MPS.DRG104
   Endif

For each .DAY from .DAYS1 in MPS.DRG104 until .DAY = .FDAYS1
Do
   Remove .DAY from the MPS.DRG104
   .MPS.NUMBER = NO1.OF.DISCHARGES(.DAY) - PRE1.NO.OF.DISCHARGES(.DAY)
   If .MPS.NUMBER <> 0
      MPS1.NUMBER = NO1.OF.DISCHARGES(.DAY)
      NUMBER1.OF.DISCHARGES = NO.OF.DISCHARGES(.DAY)
      .DAY.NUMBER = DAY.NUMBER(.DAY)
      .DAYS = .DAY
      File .DAY in the MPS.DRG104
      If P1 = 0
      .DAY.NUMBER.X = .DAY.NUMBER - (Int.f(AVGLOS.PRE.104
            + AVGLOS.POST.104 + AVGLOS.SURG.104))
         If .DAY.NUMBER.X >= Int.f(TIME.PARAMETER/24)
              - (PLANNING.PERIODICITY+1)
            For each .DAY in the MPS.DRG104
               with DAY.NUMBER(.DAY) = .DAY.NUMBER.X
               Find the first case
               If found
                  Remove .DAY from the MPS.DRG104
                  If (.DAY.NUMBER - Int.f(AVGLOS.PRE.104+AVGLOS.POST.1
                           AVGLOS.SURG.104)) > Int.f(TIME.PARAMETER/24
                      .FDAY = .DAY
                      File .DAY in the MPS.DRG104
                  Else
                     .FDAY = Int.f(TIME.PARAMETER/24)
                     File .DAY in the MPS.DRG104
                  Endif
```

```
                  Endif
            Else
               .SIGN = 1
            Endif
         Else
            .DAY.NUMBER.X = .DAY.NUMBER - (Int.f(AVGLOS.PRE.104+
                   AVGLOS.POST.104+AVGLOS.SURG.104))
            If .DAY.NUMBER.X >= Int.f(TIME.PARAMETER/24)
                   - (PLANNING.PERIODICITY +
               Int.f(AVGLOS.PRE.104))
               For each .DAY in the MPS.DRG104
                   with DAY.NUMBER(.DAY) = .DAY.NUMBER.X
                   Find the first case
               If found
                  Remove .DAY from the MPS.DRG104
                     If (.DAY.NUMBER - Int.f(AVGLOS.PRE.104+AVGLOS.POST.
                           AVGLOS.SURG.104)) > Int.f(TIME.PARAMETER/24)
                        .FDAY = .DAY
                        File .DAY in the MPS.DRG104
                     Else
                        .FDAY = Int.f(TIME.PARAMETER/24)
                        File .DAY in the MPS.DRG104
                     Endif
               Endif
            Else
               .SIGN = 1
            Endif
         Endif

      If .SIGN <> 1
      For each .DAY from .DAYS in MPS.DRG104 in reverse order until
          .DAY = .FDAY
      Do
         Remove .DAY from the MPS.DRG104
         If .DAY.NUMBER <= AVGLOS.POST.104
            .X = NO1.POST.OPERATIVE(.DAY)
            NO1.POST.OPERATIVE(.DAY) = .X + .MPS.NUMBER
            PRE1.NO.OF.DISCHARGES(.DAY) = NO1.OF.DISCHARGES(.DAY)
            Call WRITE.TRACE.MPS giving "DAY", DAY.NUMBER(.DAY),
             NO1.POST.OPERATIVE(.DAY), "post 104"
         Else
           If DAY.NUMBER(.DAY) >= 1 and DAY.NUMBER(.DAY)
                     > (.DAY.NUMBER - AVGLOS.POST.104)
             .X = NO1.POST.OPERATIVE(.DAY)
             NO1.POST.OPERATIVE(.DAY) = .X + .MPS.NUMBER
             PRE1.NO.OF.DISCHARGES(.DAY) = NO1.OF.DISCHARGES(.DAY)
             Call WRITE.TRACE.MPS giving "DAY", DAY.NUMBER(.DAY),
              NO1.POST.OPERATIVE(.DAY), "post 104"
          Else
             If DAY.NUMBER(.DAY) >= 1 and DAY.NUMBER(.DAY)
                  > (.DAY.NUMBER - (AVGLOS.POST.104 + AVGLOS.SURG.104))
                  and DAY.NUMBER(.DAY) <= (.DAY.NUMBER -
                  AVGLOS.POST.104)
               .X = NO1.SURGICAL(.DAY)
               NO1.SURGICAL(.DAY) = .X + .MPS.NUMBER
```

```
                PRE1.NO.OF.DISCHARGES(.DAY) = NO1.OF.DISCHARGES(.DAY)
                Call WRITE.TRACE.MPS giving "DAY", DAY.NUMBER(.DAY),
                 NO1.SURGICAL(.DAY), "surg 104"
             Else
                If DAY.NUMBER(.DAY) >= 1 and DAY.NUMBER(.DAY)
                    <= (.DAY.NUMBER - (AVGLOS.POST.104 + AVGLOS.SURG.104
                    and DAY.NUMBER(.DAY) <= (.DAY.NUMBER -
                    AVGLOS.POST.104)
                  .X = NO1.PRE.OPERATIVE(.DAY)
                  NO1.PRE.OPERATIVE(.DAY) = .X + .MPS.NUMBER
                  PRE1.NO.OF.DISCHARGES(.DAY) = NO1.OF.DISCHARGES(.DAY)
                  Call WRITE.TRACE.MPS giving "DAY", DAY.NUMBER(.DAY),
                  NO1.PRE.OPERATIVE(.DAY), "preop 104"
               Endif
             Endif
           Endif
         Endif
         PLAN1.RX.FOR.DAY(.DAY) = (NO1.POST.OPERATIVE(.DAY) * AVG.RX.POS
           (NO1.SURGICAL(.DAY)*AVG.RX.SURG) +(NO1.PRE.OPERATIVE(.DAY) *
           AVG.RX.PRE)
         PLAN1.BED.FOR.DAY(.DAY) = NO1.PRE.OPERATIVE(.DAY) +
           NO1.SURGICAL(.DAY) + NO1.POST.OPERATIVE(.DAY)
         File .DAY in the MPS.DRG104
       Loop
       .DAY = .DAYS
    Else
                 .SIGN = 0
            Endif
       Else
          File .DAY in the MPS.DRG104
       Endif
   Loop
   Call MPS.DRG.107
   End
```

```
''****************************
Routine CHANGE.MPS given .ID
''***************************

Define .ID as an integer variable
Define .PATIENT, .DAY as pointer variables

For each .PATIENT in the LIST.OF.PATIENTS
   with PATIENT.ID(.PATIENT) = .ID
   Find the first case
   If found
      Remove the .PATIENT from the LIST.OF.PATIENTS
      Call WRITE.Trace.LINE giving "patient", PATIENT.ID(.PATIENT), "y
      If DRG(.PATIENT) = 107
         For each .DAY in the MPS.DRG107
         with DAY.NUMBER(.DAY) = DISCHARGE.TIME.RE(.PATIENT)
         Find the first case
         If found
            Remove the .DAY from the MPS.DRG107
            Subtract 1 from NO.OF.DISCHARGES(.DAY)
            Call WRITE.TRACE.DAY giving "day", DAY.NUMBER(.DAY),
             PATIENT.ID(.PATIENT), "-1"
            File .DAY in the MPS.DRG107
            Call WRITE.TRACE.LINE giving "patient", PATIENT.ID(.PATIEN
             "discharge date DRG 107 is changed"
         Endif
         For each .DAY in the MPS.DRG107
         with DAY.NUMBER(.DAY) = DISCHARGE.TIME.RE(.PATIENT) -
         MPS.CHANGE(.PATIENT)
         Find the first case
         If found
            Remove the .DAY from the MPS.DRG107
            Add 1 to NO.OF.DISCHARGES(.DAY)
            DISCHARGE.TIME.RE(.PATIENT) = DAY.NUMBER(.DAY)
            call WRITE.TRACE.DAY giving "day", DAY.NUMBER(.DAY),
             PATIENT.ID(.PATIENT), "+1"
            File .DAY in the MPS.DRG107
         Endif
      Else
         For each .DAY in the MPS.DRG104
         with DAY.NUMBER(.DAY) = DISCHARGE.TIME.RE(.PATIENT)
         Find the first case
         If found
            Remove the .DAY from the MPS.DRG104
            Subtract 1 from NO1.OF.DISCHARGES(.DAY)
            call WRITE.TRACE.DAY giving "day", DAY.NUMBER(.DAY),
             PATIENT.ID(.PATIENT), "-1"
            File .DAY in the MPS.DRG104
            Call WRITE.TRACE.LINE giving "patient", PATIENT.ID(.PATIEN
             "discharge date DRG 104 is changed"
         Endif
         For each .DAY in the MPS.DRG104
         with DAY.NUMBER(.DAY) = DISCHARGE.TIME.RE(.PATIENT) -
               MPS.CHANGE(.PATIENT)
         Find the first case
```

```
        If found
           Remove the .DAY from the MPS.DRG104
           Add 1 to NO1.OF.DISCHARGES(.DAY)
           DISCHARGE.TIME.RE(.PATIENT) = DAY.NUMBER(.DAY)
           call WRITE.TRACE.DAY giving "day", DAY.NUMBER(.DAY),
            PATIENT.ID(.PATIENT), "+1"
           File .DAY in the MPS.DRG104
        Endif
     Endif
     File .PATIENT in the LIST.OF.PATIENTS
  Endif
End
```

```
Routine WRITE.RESULT

    Use unit 20 for output
    Print 13 lines with time.v, AVG.LENGTH.OF.STAY,
    MAX.LENGTH.OF.STAY, MIN.LENGTH.OF.STAY, DEV.LENGTH.OF.STAY,
    AVG.PRE.LOS, DEV.PRE.LOS, AVG.SURG.LOS, DEV.SURG.LOS, AVG.POST.LO
    DEV.POST.LOS thus
===============================================================================
Simulation time                               =        *****.****
Average length of stay                        =        *****.****  hours
Maximum length of stay                        =        *****.****  hours
Minimum length of stay                        =        *****.****  hours
Standard deviation of length of stay          =        *****.****  hours
Average pre-operative length of stay          =        *****.****  hours
Standard deviation of preop LOS               =        *****.****  hours
Average surgical length of stay               =        *****.****  hours
Standard deviation of surgical LOS            =        *****.****  hours
Average post-operative length of stay         =        *****.****  hours
Standard deviation of postoperative LOS =              *****.****  hours


Print 3 lines thus
Analysis per DRG
DRG CATEGORY          104           105           106           107
===============================================================================

Print 15 lines with AVG.PRE.LOS.104, AVG.PRE.LOS.105, AVG.PRE.LOS.106
    AVG.PRE.LOS.107, DEV.PRE.LOS.104, DEV.PRE.LOS.105, DEV.PRE.LOS.10
    DEV.PRE.LOS.107, AVG.SURG.LOS.104, AVG.SURG.LOS.105, AVG.SURG.LOS
    AVG.SURG.LOS.107, DEV.SURG.LOS.104, DEV.SURG.LOS.105, DEV.SURG.LO
    DEV.SURG.LOS.107, AVG.POST.LOS.104, AVG.POST.LOS.105, AVG.POST.LO
    AVG.POST.LOS.107, DEV.POST.LOS.104, DEV.POST.LOS.105, DEV.POST.LO
    DEV.POST.LOS.107, AVG.TOTAL.LOS.104, AVG.TOTAL.LOS.105, AVG.TOTAL
    AVG.TOTAL.LOS.107, DEV.TOTAL.LOS.104, DEV.TOTAL.LOS.105, DEV.TOTA
    DEV.TOTAL.LOS.107 thus
Pre-operative stage
  average        *****.**      *****.**      *****.**      *****.**
  st.dev.        *****.**      *****.**      *****.**      *****.**
Surgical stage
  average        *****.**      *****.**      *****.**      *****.**
  st.dev.        *****.**      *****.**      *****.**      *****.**
Post-operative stage
  average        *****.**      *****.**      *****.**      *****.**
  st.dev.        *****.**      *****.**      *****.**      *****.**

Total
  average        *****.**      *****.**      *****.**      *****.**
  st.dev.        *****.**      *****.**      *****.**      *****.**

================================================================================


For I = 1 to NUMBER.OF.DEPARTMENTS
Do
    For each DEPARTMENT,
```

```
        with DPT.ID(DEPARTMENT) = I
    Find the first case
    If found,
    Print 3 lines with I, AVG.UTILIZATION.DEPARTMENT thus
    DEPARTMENT **
    =============
    Mean occupancy of the department :    ******.**

    Endif
Loop

If TOTAL.EST.RX = 0
    TOTAL.EST.RX = 1
Endif
If TOTAL.EST.BED = 0
    TOTAL.EST.BED = 1
Endif
If LAT.COUNT = 0
    LAT.COUNT = 1
Endif

Print 23 lines with (AVG.PRE.RX/(AVG.PRE.LOS.107/24)),
(AVG.SURG.RX/(AVG.SURG.LOS.107/24)),
(AVG.POST.RX/(AVG.POST.LOS.107/24)), AVG.MPS.NUMBER,
AVG.MAD.RX, AVG.MAD.BED,
AVG.LATENESS, AVG.CURRENT.LAT, AVG.SQUARE.CURLAT, AVG.WAIT.BEFORE,
(BLOCK.TEL/TRANSFER) * 100, AVG.BDAYS, DISCHARGE.NUMBER,
DEV.UTILIZATION.DPT8140, DEV.UTILIZATION.DPT8327, AVG.NO.BEDS,
AVG.NO2.BEDS thus
THE AVERAGE NUMBER OF CHEST X- RAY PER STAY PER PATIENT:
==================================================================
preoperative stage                      :   ******.**
surgical stage                          :   ******.**
postoperative stage                     :   ******.**
THE AVERAGE NUMBER OF DISCHARGES IN MPS FOR DRG 107: *****.***
THE MEAN % DEVIATION IN RX REQUIREMENTS /PERIOD:                ******.**
THE MEAN % DEVIATION IN BED REQUIREMENTS /PERIOD:               ******.**
THE MEAN DEV. BETWEEN REAL AND ORIGINAL DISCHARGE DATE:         ******.**
THE MEAN DEV. BETWEEN REAL AND CURRENT DISCHARGE DATE:          ******.**
THE ROOT OF MEAN SQUARE TARDINESS:                              ******.**
THE AVG TIME BETWEEN ACTUAL AND PREFERRED ADMISSION DATE: ********.**
THE FRACTION OF TRANSFERS WHICH ARE BLOCKED:                    ******.**
PROP OF PREOP TIME DURING WHICH PATIENTS ARE BLOCKED:           ******.**
THE TOTAL NUMBER OF PATIENTS LEAVING THE HOSPITAL               ******
THE STDEV OF THE UTILISATION OF DPT.8140:                       ******.**
THE STDEV OF THE UTILISATION OF DPT.8327:                       ******.**
THE MEAN UTILISATION OF DPT.8140:                               ******.**
THE MEAN UTILISATION OF DPT.8327:                               ******.**

Print 2 lines with DEV.LATENESS.TIME, DEV.CURRENT.LATENESS, DEV.MAD.R
DEV.MAD.BED, DEV.WAIT.BEFORE, DEV.BDAYS thus
DevMadhist  DevMadcurr  DevMPDRx    DevMPDbed   Devwaitbef  Devbdays
******.**   *******.**  ******.**   *******.**  *******.**  ******.**

Reset totals of LENGTH.OF.STAY, PRE.LENGTH, SURG.LENGTH, POST.LENGTH,
```

```
PRE.RX, POST.RX, SURG.RX, MPS.NUMBER, NUMBER.OF.ADMISSIONS, DRG.HISTO
NUMBER.OF.DISCHARGES, PRE.LOS.104, POST.LOS.104, SURG.LOS.104,
PRE.LOS.105, POST.LOS.105, SURG.LOS.105, PRE.LOS.106, POST.LOS.106,
SURG.LOS.106, PRE.LOS.107, POST.LOS.107, SURG.LOS.107, TOTAL.LOS.104,
TOTAL.LOS.105, TOTAL.LOS.106, TOTAL.LOS.107, LATENESS.TIME,
CURRENT.LATENESS, WAIT.BEFORE.ADMISSION, MPD.BED.FOR.DAY,
MPD.RX.FOR.DAY, NUMBER.OF.ADMISSIONS, OCC.DPT8140, OCC.DPT8327

    TRANSFER = 0
    BLOCKTIME = 0
    BLOCK.TEL = 0
    DISCHARGE.NUMBER = 0
    LATE.NUMBER = 0
    LAT.COUNT = 0
    TOTALS.RX = 0
    TOTAL.END.TIME = 0
    RX.NO.2 = 0
    RX.NO.8 = 0
    RX.NO.83 = 0
    RX.NO.85 = 0


Use unit 6 for output

Write time.v as "Simulation time is: ", D(10,4),/
End
```

```
''**************************
Routine WRITE.MPS.RESULTS
''**************************

Define .DAY, .DAYS, .FDAYS as pointer variables
''Define .DAYADM as a pointer variable


Use unit 70 for output


Print 5 lines thus

                        MPS DRG 104/107
DAY   FORECASTREQ       PREOP        SURGICAL       POSTOP     PLAN.RX
        104     107    104    107     104   107     104   107
=====================================================================


For each .DAY in the MPS.DRG107
    with DAY.NUMBER(.DAY) = int.f(time.v/24) - 1
    Find the first case
    If found,
        Remove the .DAY from the MPS.DRG107
        .DAYS = .DAY
        File .DAY in the MPS.DRG107
    Endif
For each .DAY in the MPS.DRG107
    with DAY.NUMBER(.DAY) = int.F((TIME.PARAMETER/24) + PLANNING.HORI
    Find the first case
    If found,
        Remove the .DAY from the MPS.DRG107
        .FDAYS = .DAY
        File .DAY in the MPS.DRG107
    Endif
For each .DAY from .DAYS in the MPS.DRG107 until .DAY = .FDAYS
Do
    Remove the .DAY from the MPS.DRG107
    Remove the .DAY from the MPS.DRG104
    Print 2 lines with DAY.NUMBER(.DAY), NO1.OF.DISCHARGES(.DAY),
        NO.OF.DISCHARGES(.DAY), NO1.PRE.OPERATIVE(.DAY),
        NO.PRE.OPERATIVE(.DAY), NO1.SURGICAL(.DAY), NO.SURGICAL(.DAY)
        NO1.POST.OPERATIVE(.DAY), NO.POST.OPERATIVE(.DAY),
        PLAN.BED.FOR.DAY(.DAY)+PLAN1.BED.FOR.DAY(.DAY),
         ACTUAL.BED.FOR.DAY(.DAY) thus
******  ***    ***     ***    ***     ***   ***     ***   ***    ***.**


     File the .DAY in the MPS.DRG107
     File the .DAY in the MPS.DRG104
Loop

Use unit 6 for output
end
```

```
''**************************
Routine OPERATING.ROOM.DAT
''**************************

Use unit 25 for output

Print 3 lines with AVG.RX.POST, AVG.RX.SURG, AVG.RX.PRE thus
AVG.RX.POST   AVG.RX.SURG   AVG.RX.PRE
****.****     ****.****     ****.****

Print 7 lines with AVGLOS.PRE.104, AVGLOS.SURG.104, AVGLOS.POST.104,
  AVGLOS.PRE.107, AVGLOS.SURG.107, AVGLOS.POST.107 thus
AVGLOS.PRE.104  *****.**
AVGLOS.SURG.104 *****.**
AVGLOS.POST.104 *****.**
AVGLOS.PRE.107  *****.**
AVGLOS.SURG.107 *****.**
AVGLOS.POST.107 *****.**


Print 4 lines with HISTO.ADM(1) thus
FREQUENCY HISTOGRAM OF NUMBER OF ADMISSIONS PER DAY
    Category            frequency (admissions)
    ==========================================
       0                     *****
Print 1 line with HISTO.ADM(2) thus
       1                     *****
Print 1 line with HISTO.ADM(3) thus
       2                     *****
Print 1 line with HISTO.ADM(4) thus
       3                     *****
Print 1 line with HISTO.ADM(5) thus
       4                     *****
Print 1 line with HISTO.ADM(6) thus
       5                     *****
Print 2 lines with HISTO.ADM(7) thus
       6                     *****
--------------------------------------------------------------

Print 5 lines with HISTO.DRG(1) thus

THE DRG CASE-MIX
      DRG                 frequency
      ============================
      104                 ******
Print 2 lines with HISTO.DRG(4) thus
      107                 ******
--------------------------------------------------------------


Print 5 lines with HISTO.MPS(1) thus

MPS OF DRG 107
      NO.OF.DISCHARGES  frequency
      ============================
```

```
          0                    ******
Print 1 line with HISTO.MPS(2) thus
          1                    ******
Print 1 line with HISTO.MPS(3) thus
          2                    ******
Print 1 line with HISTO.MPS(4) thus
          3                    ******
Print 1 line with HISTO.MPS(5) thus
          4                    ******
Print 2 lines with HISTO.MPS(6) thus
          5                    ******
--------------------------------------------------------------------------
Use unit 6 for output
Reset totals of NUMBER.OF.ADMISSIONS
End
```

```
''*******************************
Routine WRITE.TRACE.LINE given
        .ENTITY,
        .ID,
        .STATE.NAME
''*******************************

    Define .ENTITY, .STATE.NAME as text variables
    Define .ID as an integer variable
    Define .TRACE.LINE as a text variable

    .TRACE.LINE = concat.f(RTOT.F(time.v)," ", .ENTITY, " ", itot.f(.I
    " ", .STATE.NAME)
    Use 60 for output
    write .TRACE.LINE as T*,/
    Use 6 for output
End
```

```
''******************************
Routine WRITE.TRACE.DAY given
        .ENTITY,
        .IDDAY,
        .IDPATIENT,
        .STATE.NAME
''******************************

        Define .ENTITY, .STATE.NAME as text variables
        Define .IDDAY, .IDPATIENT as integer variables
        Define .TRACE.LINE as a text variable

        .TRACE.LINE = concat.f(RTOT.F(time.v), " ", .ENTITY, itot.f(.
            " ", itot.f(.IDPATIENT), " ", .STATE.NAME)
        Use 80 for output
        write .TRACE.LINE as T*,/
        Use 6 for output
End
```

```
''*******************************
Routine WRITE.TRACE.MPS given
    .ENTITY,
    .ID,
    .ID1,
    .STAT.NAME
''*******************************

    Define .ENTITY, .STAT.NAME as text variables
    Define .ID, .ID1 as integer variables
    Define .TRACE.LINE as a text variable
    .TRACE.LINE = concat.F(RTOT.f(time.v), " ", .ENTITY, " ", itot.f(
       " ", itot.f(.ID1), " ", .STAT.NAME)
    Use 55 for output
    Write .TRACE.LINE as T*,/
    Use 6 for output
End
```

```
''************************
Function RTOT.F(.NUMBER)
''************************

    Define .NUMBER as a real variable
    Define .TEXT as a text variable
    Write .NUMBER as D(12,4) using the buffer
    Read .TEXT using the buffer
    Return with trim.f(.TEXT,0)
End
```

```
''***********************
Routine WRITE.RESULTS.1
''***********************

Use unit 21 for output

For each department,
    with DPT.ID(DEPARTMENT) = 2
    Find the first case
    If found,
    Print 1 line with DESIGN, time.v/1000, AVG.LENGTH.OF.STAY,
    AVG.MAD.RX, AVG.MAD.BED, AVG.LATENESS, AVG.CURRENT.LAT, AVG.WAIT.
    AVG.UTILIZATION.DEPARTMENT thus
**** ******.** ****.** ****.** ****.** ****.** ****.** ****.**  *****
    Endif

Use unit 6 for output

End
```

```
''************************
Routine WRITE.RESULTS.2
''************************


Use unit 22 for output

For each DEPARTMENT,
with DPT.ID(DEPARTMENT) = 4
Find the first case
If found,
Print 1 line with DESIGN, time.v/1000, AVG.UTILIZATION.DEPARTMENT/ICU.
     BLOCK.TEL/TRANSFER, AVG.BDAYS, DISCHARGE.NUMBER, AVG.SQUARE.CURLA
     DEV.UTILIZATION.DPT8140, DEV.UTILIZATION.DPT8327 thus
***** ******.** ****.** ******.**  ****.** ******* ******.**  ***.**
Endif

Use unit 6 for output

End
```

APPENDIX 9

SELECTED STATISTICAL TABLES

APPENDIX 9 SELECTED STATISTICAL TABLES

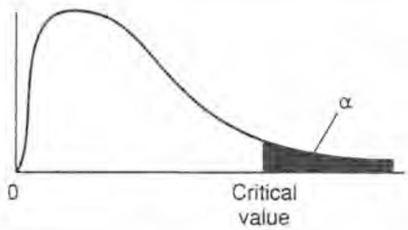
Table 1 Areas of the standard normal distribution

Second Decimal Place in z

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0.0	0.0000	0.0040	0.0080	0.0120	0.0160	0.0199	0.0239	0.0279	0.0319	0.0359
0.1	0.0398	0.0438	0.0478	0.0517	0.0557	0.0596	0.0636	0.0675	0.0714	0.0753
0.2	0.0793	0.0832	0.0871	0.0910	0.0948	0.0987	0.1026	0.1064	0.1103	0.1141
0.3	0.1179	0.1217	0.1255	0.1293	0.1331	0.1368	0.1406	0.1443	0.1480	0.1517
0.4	0.1554	0.1591	0.1628	0.1664	0.1700	0.1736	0.1772	0.1808	0.1844	0.1879
0.5	0.1915	0.1950	0.1985	0.2019	0.2054	0.2088	0.2123	0.2157	0.2190	0.2224
0.6	0.2257	0.2291	0.2324	0.2357	0.2389	0.2422	0.2454	0.2486	0.2517	0.2549
0.7	0.2580	0.2611	0.2642	0.2673	0.2704	0.2734	0.2764	0.2794	0.2823	0.2852
0.8	0.2881	0.2910	0.2939	0.2967	0.2995	0.3023	0.3051	0.3078	0.3106	0.3133
0.9	0.3159	0.3186	0.3212	0.3238	0.3264	0.3289	0.3315	0.3340	0.3365	0.3389
1.0	0.3413	0.3438	0.3461	0.3485	0.3508	0.3531	0.3554	0.3577	0.3599	0.3621
1.1	0.3643	0.3665	0.3686	0.3708	0.3729	0.3749	0.3770	0.3790	0.3810	0.3830
1.2	0.3849	0.3869	0.3888	0.3907	0.3925	0.3944	0.3962	0.3980	0.3997	0.4015
1.3	0.4032	0.4049	0.4066	0.4082	0.4099	0.4115	0.4131	0.4147	0.4162	0.4177
1.4	0.4192	0.4207	0.4222	0.4236	0.4251	0.4265	0.4279	0.4292	0.4306	0.4319
1.5	0.4332	0.4345	0.4357	0.4370	0.4382	0.4394	0.4406	0.4418	0.4429	0.4441
1.6	0.4452	0.4463	0.4474	0.4484	0.4495	0.4505	0.4515	0.4525	0.4535	0.4545
1.7	0.4554	0.4564	0.4573	0.4582	0.4591	0.4599	0.4608	0.4616	0.4625	0.4633
1.8	0.4641	0.4649	0.4656	0.4664	0.4671	0.4678	0.4686	0.4693	0.4699	0.4706
1.9	0.4713	0.4719	0.4726	0.4732	0.4738	0.4744	0.4750	0.4756	0.4761	0.4767
2.0	0.4772	0.4778	0.4783	0.4788	0.4793	0.4798	0.4803	0.4808	0.4812	0.4817
2.1	0.4821	0.4826	0.4830	0.4834	0.4838	0.4842	0.4846	0.4850	0.4854	0.4857
2.2	0.4861	0.4864	0.4868	0.4871	0.4875	0.4878	0.4881	0.4884	0.4887	0.4890
2.3	0.4893	0.4896	0.4898	0.4901	0.4904	0.4906	0.4909	0.4911	0.4913	0.4916
2.4	0.4918	0.4920	0.4922	0.4925	0.4927	0.4929	0.4931	0.4932	0.4934	0.4936
2.5	0.4938	0.4940	0.4941	0.4943	0.4945	0.4946	0.4948	0.4949	0.4951	0.4952
2.6	0.4953	0.4955	0.4956	0.4957	0.4959	0.4960	0.4961	0.4962	0.4963	0.4964
2.7	0.4965	0.4966	0.4967	0.4968	0.4969	0.4970	0.4971	0.4972	0.4973	0.4974
2.8	0.4974	0.4975	0.4976	0.4977	0.4977	0.4978	0.4979	0.4979	0.4980	0.4981
2.9	0.4981	0.4982	0.4982	0.4983	0.4984	0.4984	0.4985	0.4985	0.4986	0.4986
3.0	0.4987	0.4987	0.4987	0.4988	0.4988	0.4989	0.4989	0.4989	0.4990	0.4990
3.1	0.4990	0.4991	0.4991	0.4991	0.4992	0.4992	0.4992	0.4992	0.4993	0.4993
3.2	0.4993	0.4993	0.4994	0.4994	0.4994	0.4994	0.4994	0.4995	0.4995	0.4995
3.3	0.4995	0.4995	0.4995	0.4996	0.4996	0.4996	0.4996	0.4996	0.4996	0.4997
3.4	0.4997	0.4997	0.4997	0.4997	0.4997	0.4997	0.4997	0.4997	0.4997	0.4998
3.5	0.4998									
4.0	0.49997									
4.5	0.499997									
5.0	0.4999997									
6.0	0.499999999									

APPENDIX 9 continued

Table 2 Critical values of the Chi-square distribution



df	Probability under H_0 that $\chi^2 \geqq$ Chi Square				
	.10	.05	.02	.01	.001
1	2.71	3.84	5.41	6.64	10.83
2	4.60	5.99	7.82	9.21	13.82
3	6.25	7.82	9.84	11.34	16.27
4	7.78	9.49	11.67	13.28	18.46
5	9.24	11.07	13.39	15.09	20.52
6	10.64	12.59	15.03	16.81	22.46
7	12.02	14.07	16.62	18.48	24.32
8	13.36	15.51	18.17	20.09	26.12
9	14.68	16.92	19.68	21.67	27.88
10	15.99	18.31	21.16	23.21	29.59
11	17.28	19.68	22.62	24.72	31.26
12	18.55	21.03	24.05	26.22	32.91
13	19.81	22.36	25.47	27.69	34.53
14	21.06	23.68	26.87	29.14	36.12
15	22.31	25.00	28.26	30.58	37.70
16	23.54	26.30	29.63	32.00	39.29
17	24.77	27.59	31.00	33.41	40.75
18	25.99	28.87	32.35	34.80	42.31
19	27.20	30.14	33.69	36.19	43.82
20	28.41	31.41	35.02	37.57	45.32
21	29.62	32.67	36.34	38.93	46.80
22	30.81	33.92	37.66	40.29	48.27
23	32.01	35.17	38.97	41.64	49.73
24	33.20	36.42	40.27	42.98	51.18
25	34.38	37.65	41.57	44.31	52.62
26	35.56	38.88	42.86	45.64	54.05
27	36.74	40.11	44.14	46.96	55.48
28	37.92	41.34	45.42	48.28	56.89
29	39.09	42.56	46.69	49.59	58.30
30	40.26	43.77	47.96	50.89	59.70

Source: Abridged from Table IV of Fisher and Yates, *Statistics for Biological, Agricultural, and Medical Research*, published by Oliver and Boyd Ltd., Edinburgh, 1963. By permission of the publishers.

APPENDIX 9 continued

Table 3 Critical values of T in the Wilcoxon Matched-Pairs test

N	*Level of Significance for One-Tailed Test*		
	.025	.01	.005
	Level of Significance for Two-Tailed Test		
	.05	.02	.01
6	0	—	—
7	2	0	—
8	4	2	0
9	6	3	2
10	8	5	3
11	11	7	5
12	14	10	7
13	17	13	10
14	21	16	13
15	25	20	16
16	30	24	20
17	35	28	23
18	40	33	28
19	46	38	32
20	52	43	38
21	59	49	43
22	66	56	49
23	73	62	55
24	81	69	61
25	89	77	68

Source: Adapted from Table I of F. Wilcoxon, *Some Rapid Approximate Statistical Procedures* (New York: American Cyanamid Company, 1949), p. 13, with the kind permission of the publisher.

APPENDIX 9 continued

Table 4 Critical values of D in the Kolmogorov-Smirnov one-sample test

Sample Size N	Level of Significance for $D = \text{Maximum } \lvert F_0(X) - S_N(X) \rvert$				
	.20	.15	.10	.05	.01
1	.900	.925	.950	.975	.995
2	.684	.726	.776	.842	.929
3	.565	.597	.642	.708	.828
4	.494	.525	.564	.624	.733
5	.446	.474	.510	.565	.669
6	.410	.436	.470	.521	.618
7	.381	.405	.438	.486	.577
8	.358	.381	.411	.457	.543
9	.339	.360	.388	.432	.514
10	.322	.342	.368	.410	.490
11	.307	.326	.352	.391	.468
12	.295	.313	.338	.375	.450
13	.284	.302	.325	.361	.433
14	.274	.292	.314	.349	.418
15	.266	.283	.304	.338	.404
16	.258	.274	.295	.328	.392
17	.250	.266	.286	.318	.381
18	.244	.259	.278	.309	.371
19	.237	.252	.272	.301	.363
20	.231	.246	.264	.294	.356
25	.21	.22	.24	.27	.32
30	.19	.20	.22	.24	.29
35	.18	.19	.21	.23	.27
Over 35	$\frac{1.07}{\sqrt{N}}$	$\frac{1.14}{\sqrt{N}}$	$\frac{1.22}{\sqrt{N}}$.	$\frac{1.36}{\sqrt{N}}$	$\frac{1.63}{\sqrt{N}}$

Source: F. J. Massey, Jr., "The Kolmogorov-Smirnov Test for Goodness of Fit," *Journal of the American Statistical Association*, 46, p. 70. Adapted with the kind permission of the publisher.

APPENDIX 10

RESULTS OF THE SIMULATION: ANOVA-RESULTS, MAIN EFFECTS AND INTERACTION EFFECTS

APPENDIX 10 RESULTS OF THE SIMULATION: ANOVA-RESULTS, MAIN EFFECTS AND INTERACTION EFFECTS

1.ANOVA: summary of all effects

Explanation for symbols in the tables on the next pages:

Casename = kind of effect; e.g. 1 = Main effect of dynamic order due date maintenance and 12 = interaction effect between dynamic order due date maintenance and capacity limits.

1 = dynamic order due date maintenance
2 = capacity limits
3 = leadtime uncertainty
4 = safety leadtime
5 = emergencies
6 = classification error
7 = planning frequency

Df effect = degrees of freedom related to the between-groups variability

MS effect = the mean square effect or the variance due to the between-groups variability

Df error = degrees of freedom related to the within-group variability

MS error = the mean square error or the variance due to within-group variability

F = F statistic

p-level = the level of significance for the F-test which tests whether the ratio of the two variance estimates is significantly greater than 1.

Summary of all effects for MPDBED						
CASENAME	DF_EFFEC	MS_EFFEC	DF_ERROR	MS_ERROR	F	P_LEVEL
1	1,00	124,35	512,00	5,91	21,06	0,0000
2	1,00	1048,65	512,00	5,91	177,58	0,0000
3	1,00	73,73	512,00	5,91	12,49	0,0004
4	1,00	1961,09	512,00	5,91	332,09	0,0000
5	1,00	54,60	512,00	5,91	9,25	0,0025
6	1,00	10,18	512,00	5,91	1,72	0,1897
7	1,00	393,74	512,00	5,91	66,68	0,0000
12	1,00	0,81	512,00	5,91	0,14	0,7117
13	1,00	84,76	512,00	5,91	14,35	0,0002
23	1,00	37,68	512,00	5,91	6,38	0,0118
14	1,00	69,97	512,00	5,91	11,85	0,0006
24	1,00	177,34	512,00	5,91	30,03	0,0000
34	1,00	1,66	512,00	5,91	0,28	0,5963
15	1,00	2,78	512,00	5,91	0,47	0,4926
25	1,00	95,83	512,00	5,91	16,23	0,0001
35	1,00	1,21	512,00	5,91	0,21	0,6507
45	1,00	2,34	512,00	5,91	0,40	0,5294
16	1,00	128,96	512,00	5,91	21,84	0,0000
26	1,00	75,69	512,00	5,91	12,82	0,0004
36	1,00	12,18	512,00	5,91	2,06	0,1516
46	1,00	60,07	512,00	5,91	10,17	0,0015
56	1,00	2,20	512,00	5,91	0,37	0,5422
17	1,00	821,76	512,00	5,91	139,16	0,0000
27	1,00	21,31	512,00	5,91	3,61	0,0580
37	1,00	53,45	512,00	5,91	9,05	0,0028
47	1,00	293,51	512,00	5,91	49,70	0,0000
57	1,00	0,44	512,00	5,91	0,07	0,7851
67	1,00	1,26	512,00	5,91	0,21	0,6440
123	1,00	106,97	512,00	5,91	18,11	0,0000
124	1,00	1,88	512,00	5,91	0,32	0,5728
134	1,00	66,03	512,00	5,91	11,18	0,0009
234	1,00	23,07	512,00	5,91	3,91	0,0486
125	1,00	3,27	512,00	5,91	0,55	0,4571
135	1,00	12,52	512,00	5,91	2,12	0,1460
235	1,00	40,10	512,00	5,91	6,79	0,0094
145	1,00	4,77	512,00	5,91	0,81	0,3694
245	1,00	38,12	512,00	5,91	6,45	0,0114
345	1,00	3,89	512,00	5,91	0,66	0,4176
126	1,00	2,67	512,00	5,91	0,45	0,5017
136	1,00	5,80	512,00	5,91	0,98	0,3223

CASENAME	DF_EFFEC	MS_EFFEC	DF_ERROR	MS_ERROR	F	P_LEVEL
236	1,00	0,05	512,00	5,91	0,01	0,9245
146	1,00	83,57	512,00	5,91	14,15	0,0002
246	1,00	75,01	512,00	5,91	12,70	0,0004
346	1,00	3,66	512,00	5,91	0,62	0,4314
156	1,00	7,49	512,00	5,91	1,27	0,2605
256	1,00	6,83	512,00	5,91	1,16	0,2827
356	1,00	7,91	512,00	5,91	1,34	0,2475
456	1,00	2,93	512,00	5,91	0,50	0,4818
127	1,00	10,99	512,00	5,91	1,86	0,1731
137	1,00	3,87	512,00	5,91	0,66	0,4186
237	1,00	0,75	512,00	5,91	0,13	0,7219
147	1,00	56,42	512,00	5,91	9,55	0,0021
247	1,00	104,76	512,00	5,91	17,74	0,0000
347	1,00	18,39	512,00	5,91	3,11	0,0782
157	1,00	2,21	512,00	5,91	0,37	0,5407
257	1,00	54,83	512,00	5,91	9,29	0,0024
357	1,00	1,60	512,00	5,91	0,27	0,6028
457	1,00	365,86	512,00	5,91	61,96	0,0000
167	1,00	21,09	512,00	5,91	3,57	0,0593
267	1,00	2,27	512,00	5,91	0,38	0,5354
367	1,00	1,02	512,00	5,91	0,17	0,6774
467	1,00	51,74	512,00	5,91	8,76	0,0032
567	1,00	10,54	512,00	5,91	1,78	0,1822
1234	1,00	119,74	512,00	5,91	20,28	0,0000
1235	1,00	0,80	512,00	5,91	0,13	0,7137
1245	1,00	9,12	512,00	5,91	1,54	0,2145
1345	1,00	50,25	512,00	5,91	8,51	0,0037
2345	1,00	6,01	512,00	5,91	1,02	0,3136
1236	1,00	3,94	512,00	5,91	0,67	0,4145
1246	1,00	21,92	512,00	5,91	3,71	0,0546
1346	1,00	0,21	512,00	5,91	0,04	0,8505
2346	1,00	35,92	512,00	5,91	6,08	0,0140
1256	1,00	88,45	512,00	5,91	14,98	0,0001
1356	1,00	26,61	512,00	5,91	4,51	0,0342
2356	1,00	5,20	512,00	5,91	0,88	0,3486
1456	1,00	3,21	512,00	5,91	0,54	0,4610
2456	1,00	38,38	512,00	5,91	6,50	0,0111
3456	1,00	14,48	512,00	5,91	2,45	0,1180
1237	1,00	63,35	512,00	5,91	10,73	0,0011
1247	1,00	24,43	512,00	5,91	4,14	0,0425
1347	1,00	106,66	512,00	5,91	18,06	0,0000
2347	1,00	1,26	512,00	5,91	0,21	0,6437
1257	1,00	73,29	512,00	5,91	12,41	0,0005
1357	1,00	2,93	512,00	5,91	0,50	0,4818

CASENAME	DF_EFFEC	MS_EFFEC	DF_ERROR	MS_ERROR	F	P_LEVEL
2357	1,00	26,78	512,00	5,91	4,53	0,0337
1457	1,00	48,28	512,00	5,91	8,18	0,0044
2457	1,00	4,78	512,00	5,91	0,81	0,3685
3457	1,00	21,60	512,00	5,91	3,66	0,0564
1267	1,00	8,78	512,00	5,91	1,49	0,2232
1367	1,00	2,01	512,00	5,91	0,34	0,5594
2367	1,00	28,34	512,00	5,91	4,80	0,0289
1467	1,00	27,44	512,00	5,91	4,65	0,0316
2467	1,00	0,20	512,00	5,91	0,03	0,8549
3467	1,00	10,55	512,00	5,91	1,79	0,1818
1567	1,00	0,00	512,00	5,91	0,00	0,9944
2567	1,00	6,83	512,00	5,91	1,16	0,2826
3567	1,00	187,95	512,00	5,91	31,83	0,0000
4567	1,00	6,82	512,00	5,91	1,16	0,2829
12345	1,00	2,08	512,00	5,91	0,35	0,5529
12346	1,00	34,29	512,00	5,91	5,81	0,0163
12356	1,00	0,07	512,00	5,91	0,01	0,9147
12456	1,00	35,02	512,00	5,91	5,93	0,0152
13456	1,00	14,31	512,00	5,91	2,42	0,1201
23456	1,00	7,24	512,00	5,91	1,23	0,2687
12347	1,00	44,23	512,00	5,91	7,49	0,0064
12357	1,00	21,49	512,00	5,91	3,64	0,0570
12457	1,00	8,74	512,00	5,91	1,48	0,2243
13457	1,00	0,00	512,00	5,91	0,00	0,9942
23457	1,00	24,09	512,00	5,91	4,08	0,0439
12367	1,00	6,94	512,00	5,91	1,17	0,2789
12467	1,00	35,72	512,00	5,91	6,05	0,0142
13467	1,00	25,78	512,00	5,91	4,37	0,0372
23467	1,00	0,57	512,00	5,91	0,10	0,7560
12567	1,00	100,99	512,00	5,91	17,10	0,0000
13567	1,00	32,60	512,00	5,91	5,52	0,0192
23567	1,00	11,79	512,00	5,91	2,00	0,1582
14567	1,00	0,24	512,00	5,91	0,04	0,8414
24567	1,00	38,69	512,00	5,91	6,55	0,0108
34567	1,00	13,87	512,00	5,91	2,35	0,1260
123456	1,00	16,07	512,00	5,91	2,72	0,0996
123457	1,00	26,17	512,00	5,91	4,43	0,0358
123467	1,00	1,84	512,00	5,91	0,31	0,5775
123567	1,00	7,56	512,00	5,91	1,28	0,2584
124567	1,00	242,32	512,00	5,91	41,04	0,0000
134567	1,00	13,28	512,00	5,91	2,25	0,1343
234567	1,00	6,69	512,00	5,91	1,13	0,2875
1234567	1,00	30,22	512,00	5,91	5,12	0,0241

Summary of all effects for MPDRX						
CASENAME	DF_EFFEC	MS_EFFEC	DF_ERROR	MS_ERROR	F	P_LEVEL
1	1,00	201,19	512,00	10,73	18,75	0,0000
2	1,00	304,83	512,00	10,73	28,41	0,0000
3	1,00	40,08	512,00	10,73	3,73	0,0538
4	1,00	9543,85	512,00	10,73	889,39	0,0000
5	1,00	489,42	512,00	10,73	45,61	0,0000
6	1,00	201,34	512,00	10,73	18,76	0,0000
7	1,00	10166,93	512,00	10,73	947,45	0,0000
12	1,00	75,07	512,00	10,73	7,00	0,0084
13	1,00	9,26	512,00	10,73	0,86	0,3533
23	1,00	24,28	512,00	10,73	2,26	0,1332
14	1,00	416,82	512,00	10,73	38,84	0,0000
24	1,00	107,97	512,00	10,73	10,06	0,0016
34	1,00	1,49	512,00	10,73	0,14	0,7100
15	1,00	25,83	512,00	10,73	2,41	0,1214
25	1,00	94,00	512,00	10,73	8,76	0,0032
35	1,00	4,67	512,00	10,73	0,43	0,5099
45	1,00	63,54	512,00	10,73	5,92	0,0153
16	1,00	407,92	512,00	10,73	38,01	0,0000
26	1,00	57,35	512,00	10,73	5,34	0,0212
36	1,00	3,40	512,00	10,73	0,32	0,5737
46	1,00	214,68	512,00	10,73	20,01	0,0000
56	1,00	104,56	512,00	10,73	9,74	0,0019
17	1,00	6236,94	512,00	10,73	581,22	0,0000
27	1,00	77,56	512,00	10,73	7,23	0,0074
37	1,00	136,13	512,00	10,73	12,69	0,0004
47	1,00	1791,55	512,00	10,73	166,95	0,0000
57	1,00	320,48	512,00	10,73	29,87	0,0000
67	1,00	519,46	512,00	10,73	48,41	0,0000
123	1,00	0,20	512,00	10,73	0,02	0,8907
124	1,00	120,35	512,00	10,73	11,22	0,0009
134	1,00	50,00	512,00	10,73	4,66	0,0313
234	1,00	0,33	512,00	10,73	0,03	0,8599
125	1,00	47,88	512,00	10,73	4,46	0,0351
135	1,00	9,87	512,00	10,73	0,92	0,3380
235	1,00	15,46	512,00	10,73	1,44	0,2306
145	1,00	1,14	512,00	10,73	0,11	0,7448
245	1,00	48,19	512,00	10,73	4,49	0,0346
345	1,00	9,53	512,00	10,73	0,89	0,3464
126	1,00	379,96	512,00	10,73	35,41	0,0000
136	1,00	56,85	512,00	10,73	5,30	0,0217
236	1,00	35,28	512,00	10,73	3,29	0,0704
146	1,00	22,37	512,00	10,73	2,08	0,1494

CASENAME	DF_EFFEC	MS_EFFEC	DF_ERROR	MS_ERROR	F	P_LEVEL
246	1,00	0,42	512,00	10,73	0,04	0,8441
346	1,00	0,18	512,00	10,73	0,02	0,8976
156	1,00	13,72	512,00	10,73	1,28	0,2587
256	1,00	1,61	512,00	10,73	0,15	0,6988
356	1,00	0,05	512,00	10,73	0,00	0,9455
456	1,00	4,65	512,00	10,73	0,43	0,5107
127	1,00	25,84	512,00	10,73	2,41	0,1213
137	1,00	8,90	512,00	10,73	0,83	0,3629
237	1,00	91,17	512,00	10,73	8,50	0,0037
147	1,00	142,25	512,00	10,73	13,26	0,0003
247	1,00	298,57	512,00	10,73	27,82	0,0000
347	1,00	58,65	512,00	10,73	5,47	0,0198
157	1,00	88,53	512,00	10,73	8,25	0,0042
257	1,00	206,04	512,00	10,73	19,20	0,0000
357	1,00	13,82	512,00	10,73	1,29	0,2571
457	1,00	34,76	512,00	10,73	3,24	0,0725
167	1,00	227,64	512,00	10,73	21,21	0,0000
267	1,00	82,46	512,00	10,73	7,68	0,0058
367	1,00	7,24	512,00	10,73	0,67	0,4118
467	1,00	0,18	512,00	10,73	0,02	0,8965
567	1,00	0,15	512,00	10,73	0,01	0,9056
1234	1,00	32,93	512,00	10,73	3,07	0,0804
1235	1,00	30,25	512,00	10,73	2,82	0,0938
1245	1,00	21,61	512,00	10,73	2,01	0,1565
1345	1,00	31,48	512,00	10,73	2,93	0,0874
2345	1,00	5,49	512,00	10,73	0,51	0,4750
1236	1,00	48,27	512,00	10,73	4,50	0,0344
1246	1,00	220,32	512,00	10,73	20,53	0,0000
1346	1,00	1,36	512,00	10,73	0,13	0,7225
2346	1,00	4,81	512,00	10,73	0,45	0,5034
1256	1,00	91,44	512,00	10,73	8,52	0,0037
1356	1,00	302,79	512,00	10,73	28,22	0,0000
2356	1,00	40,01	512,00	10,73	3,73	0,0541
1456	1,00	2,88	512,00	10,73	0,27	0,6045
2456	1,00	17,85	512,00	10,73	1,66	0,1977
3456	1,00	144,50	512,00	10,73	13,47	0,0003
1237	1,00	5,29	512,00	10,73	0,49	0,4827
1247	1,00	7,11	512,00	10,73	0,66	0,4159
1347	1,00	10,76	512,00	10,73	1,00	0,3172
2347	1,00	3,18	512,00	10,73	0,30	0,5866
1257	1,00	60,73	512,00	10,73	5,66	0,0177
1357	1,00	4,43	512,00	10,73	0,41	0,5210
2357	1,00	14,14	512,00	10,73	1,32	0,2515
1457	1,00	0,10	512,00	10,73	0,01	0,9230

CASENAME	DF_EFFEC	MS_EFFEC	DF_ERROR	MS_ERROR	F	P_LEVEL
2457	1,00	100,61	512,00	10,73	9,38	0,0023
3457	1,00	98,42	512,00	10,73	9,17	0,0026
1267	1,00	266,14	512,00	10,73	24,80	0,0000
1367	1,00	128,17	512,00	10,73	11,94	0,0006
2367	1,00	22,99	512,00	10,73	2,14	0,1439
1467	1,00	288,30	512,00	10,73	26,87	0,0000
2467	1,00	87,64	512,00	10,73	8,17	0,0044
3467	1,00	9,15	512,00	10,73	0,85	0,3563
1567	1,00	107,04	512,00	10,73	9,97	0,0017
2567	1,00	70,78	512,00	10,73	6,60	0,0105
3567	1,00	0,11	512,00	10,73	0,01	0,9202
4567	1,00	0,08	512,00	10,73	0,01	0,9303
12345	1,00	28,76	512,00	10,73	2,68	0,1022
12346	1,00	11,54	512,00	10,73	1,08	0,3003
12356	1,00	144,73	512,00	10,73	13,49	0,0003
12456	1,00	0,74	512,00	10,73	0,07	0,7936
13456	1,00	14,83	512,00	10,73	1,38	0,2403
23456	1,00	12,93	512,00	10,73	1,20	0,2728
12347	1,00	92,01	512,00	10,73	8,57	0,0036
12357	1,00	67,39	512,00	10,73	6,28	0,0125
12457	1,00	9,77	512,00	10,73	0,91	0,3405
13457	1,00	12,50	512,00	10,73	1,16	0,2810
23457	1,00	32,14	512,00	10,73	3,00	0,0841
12367	1,00	32,13	512,00	10,73	2,99	0,0842
12467	1,00	246,43	512,00	10,73	22,96	0,0000
13467	1,00	2,03	512,00	10,73	0,19	0,6639
23467	1,00	43,21	512,00	10,73	4,03	0,0453
12567	1,00	3,63	512,00	10,73	0,34	0,5613
13567	1,00	185,66	512,00	10,73	17,30	0,0000
23567	1,00	22,29	512,00	10,73	2,08	0,1501
14567	1,00	3,08	512,00	10,73	0,29	0,5924
24567	1,00	56,76	512,00	10,73	5,29	0,0219
34567	1,00	193,48	512,00	10,73	18,03	0,0000
123456	1,00	33,10	512,00	10,73	3,08	0,0796
123457	1,00	10,63	512,00	10,73	0,99	0,3200
123467	1,00	5,38	512,00	10,73	0,50	0,4791
123567	1,00	153,83	512,00	10,73	14,34	0,0002
124567	1,00	35,57	512,00	10,73	3,31	0,0693
134567	1,00	1,63	512,00	10,73	0,15	0,6970
234567	1,00	96,03	512,00	10,73	8,95	0,0029
1234567	1,00	1,14	512,00	10,73	0,11	0,7442

Summary of all effects for MADHIST						
CASENAME	DF_EFFEC	MS_EFFEC	DF_ERROR	MS_ERROR	F	P_LEVEL
1	1,00	1,09	512,00	0,20	5,35	0,0211
2	1,00	23,70	512,00	0,20	116,64	0,0000
3	1,00	0,01	512,00	0,20	0,05	0,8184
4	1,00	152,33	512,00	0,20	749,70	0,0000
5	1,00	0,99	512,00	0,20	4,88	0,0277
6	1,00	28,19	512,00	0,20	138,74	0,0000
7	1,00	0,27	512,00	0,20	1,31	0,2534
12	1,00	1,29	512,00	0,20	6,35	0,0120
13	1,00	1,82	512,00	0,20	8,95	0,0029
23	1,00	0,39	512,00	0,20	1,90	0,1692
14	1,00	0,96	512,00	0,20	4,71	0,0305
24	1,00	0,35	512,00	0,20	1,74	0,1878
34	1,00	0,14	512,00	0,20	0,67	0,4131
15	1,00	2,04	512,00	0,20	10,03	0,0016
25	1,00	0,98	512,00	0,20	4,81	0,0287
35	1,00	0,06	512,00	0,20	0,27	0,6015
45	1,00	1,00	512,00	0,20	4,92	0,0270
16	1,00	0,36	512,00	0,20	1,79	0,1814
26	1,00	0,07	512,00	0,20	0,33	0,5630
36	1,00	0,12	512,00	0,20	0,60	0,4396
46	1,00	0,00	512,00	0,20	0,00	0,9441
56	1,00	1,74	512,00	0,20	8,55	0,0036
17	1,00	0,23	512,00	0,20	1,16	0,2828
27	1,00	1,99	512,00	0,20	9,79	0,0019
37	1,00	2,52	512,00	0,20	12,41	0,0005
47	1,00	0,38	512,00	0,20	1,89	0,1697
57	1,00	0,98	512,00	0,20	4,83	0,0284
67	1,00	0,06	512,00	0,20	0,31	0,5749
123	1,00	0,88	512,00	0,20	4,31	0,0383
124	1,00	2,11	512,00	0,20	10,38	0,0014
134	1,00	2,63	512,00	0,20	12,95	0,0004
234	1,00	0,93	512,00	0,20	4,60	0,0324
125	1,00	0,01	512,00	0,20	0,07	0,7872
135	1,00	0,01	512,00	0,20	0,06	0,8075
235	1,00	0,47	512,00	0,20	2,31	0,1294
145	1,00	2,28	512,00	0,20	11,22	0,0009
245	1,00	3,73	512,00	0,20	18,36	0,0000
345	1,00	0,82	512,00	0,20	4,03	0,0453
126	1,00	0,37	512,00	0,20	1,81	0,1792
136	1,00	0,14	512,00	0,20	0,69	0,4062
236	1,00	0,40	512,00	0,20	1,98	0,1596
146	1,00	1,17	512,00	0,20	5,76	0,0167

CASENAME	DF_EFFEC	MS_EFFEC	DF_ERROR	MS_ERROR	F	P_LEVEL
246	1,00	1,63	512,00	0,20	8,03	0,0048
346	1,00	0,68	512,00	0,20	3,33	0,0685
156	1,00	0,05	512,00	0,20	0,22	0,6360
256	1,00	0,62	512,00	0,20	3,05	0,0816
356	1,00	0,34	512,00	0,20	1,66	0,1986
456	1,00	0,27	512,00	0,20	1,34	0,2469
127	1,00	0,04	512,00	0,20	0,18	0,6727
137	1,00	0,01	512,00	0,20	0,04	0,8389
237	1,00	0,53	512,00	0,20	2,63	0,1054
147	1,00	1,24	512,00	0,20	6,12	0,0137
247	1,00	0,01	512,00	0,20	0,02	0,8746
347	1,00	0,83	512,00	0,20	4,09	0,0437
157	1,00	0,03	512,00	0,20	0,16	0,6894
257	1,00	0,72	512,00	0,20	3,55	0,0599
357	1,00	0,01	512,00	0,20	0,04	0,8361
457	1,00	0,53	512,00	0,20	2,62	0,1061
167	1,00	1,08	512,00	0,20	5,34	0,0213
267	1,00	0,97	512,00	0,20	4,79	0,0291
367	1,00	0,05	512,00	0,20	0,24	0,6248
467	1,00	1,12	512,00	0,20	5,52	0,0191
567	1,00	0,03	512,00	0,20	0,12	0,7246
1234	1,00	0,06	512,00	0,20	0,29	0,5893
1235	1,00	1,46	512,00	0,20	7,21	0,0075
1245	1,00	0,20	512,00	0,20	0,98	0,3231
1345	1,00	0,20	512,00	0,20	0,97	0,3256
2345	1,00	0,25	512,00	0,20	1,22	0,2697
1236	1,00	0,57	512,00	0,20	2,81	0,0942
1246	1,00	0,95	512,00	0,20	4,66	0,0313
1346	1,00	0,21	512,00	0,20	1,02	0,3129
2346	1,00	3,50	512,00	0,20	17,20	0,0000
1256	1,00	0,37	512,00	0,20	1,80	0,1797
1356	1,00	0,00	512,00	0,20	0,02	0,8899
2356	1,00	0,02	512,00	0,20	0,10	0,7497
1456	1,00	0,74	512,00	0,20	3,65	0,0565
2456	1,00	0,70	512,00	0,20	3,42	0,0648
3456	1,00	0,04	512,00	0,20	0,18	0,6689
1237	1,00	1,13	512,00	0,20	5,56	0,0188
1247	1,00	1,45	512,00	0,20	7,15	0,0077
1347	1,00	0,00	512,00	0,20	0,01	0,9357
2347	1,00	0,03	512,00	0,20	0,15	0,7011
1257	1,00	1,22	512,00	0,20	6,01	0,0145
1357	1,00	0,01	512,00	0,20	0,03	0,8622
2357	1,00	7,21	512,00	0,20	35,47	0,0000
1457	1,00	0,00	512,00	0,20	0,00	0,9497

CASENAME	DF_EFFEC	MS_EFFEC	DF_ERROR	MS_ERROR	F	P_LEVEL
2457	1,00	0,23	512,00	0,20	1,12	0,2908
3457	1,00	0,02	512,00	0,20	0,07	0,7845
1267	1,00	0,39	512,00	0,20	1,93	0,1649
1367	1,00	0,71	512,00	0,20	3,48	0,0626
2367	1,00	2,28	512,00	0,20	11,21	0,0009
1467	1,00	0,19	512,00	0,20	0,93	0,3343
2467	1,00	0,91	512,00	0,20	4,47	0,0349
3467	1,00	0,19	512,00	0,20	0,92	0,3378
1567	1,00	0,04	512,00	0,20	0,21	0,6436
2567	1,00	0,03	512,00	0,20	0,14	0,7063
3567	1,00	0,03	512,00	0,20	0,13	0,7233
4567	1,00	0,17	512,00	0,20	0,83	0,3613
12345	1,00	1,51	512,00	0,20	7,42	0,0067
12346	1,00	0,05	512,00	0,20	0,23	0,6286
12356	1,00	0,05	512,00	0,20	0,27	0,6051
12456	1,00	3,29	512,00	0,20	16,21	0,0001
13456	1,00	0,24	512,00	0,20	1,17	0,2797
23456	1,00	0,57	512,00	0,20	2,82	0,0935
12347	1,00	1,38	512,00	0,20	6,77	0,0095
12357	1,00	0,97	512,00	0,20	4,75	0,0297
12457	1,00	0,00	512,00	0,20	0,00	0,9720
13457	1,00	0,00	512,00	0,20	0,02	0,8926
23457	1,00	2,79	512,00	0,20	13,72	0,0002
12367	1,00	0,05	512,00	0,20	0,23	0,6335
12467	1,00	0,42	512,00	0,20	2,04	0,1535
13467	1,00	0,13	512,00	0,20	0,63	0,4263
23467	1,00	0,00	512,00	0,20	0,00	0,9650
12567	1,00	0,09	512,00	0,20	0,45	0,5032
13567	1,00	0,29	512,00	0,20	1,44	0,2302
23567	1,00	0,94	512,00	0,20	4,61	0,0323
14567	1,00	0,03	512,00	0,20	0,14	0,7102
24567	1,00	0,11	512,00	0,20	0,53	0,4670
34567	1,00	0,58	512,00	0,20	2,83	0,0929
123456	1,00	0,01	512,00	0,20	0,03	0,8677
123457	1,00	0,28	512,00	0,20	1,38	0,2398
123467	1,00	0,71	512,00	0,20	3,51	0,0616
123567	1,00	0,44	512,00	0,20	2,14	0,1437
124567	1,00	1,28	512,00	0,20	6,31	0,0123
134567	1,00	0,01	512,00	0,20	0,04	0,8402
234567	1,00	0,43	512,00	0,20	2,13	0,1451
1234567	1,00	0,29	512,00	0,20	1,43	0,2329

Summary of all effects for MADCUR						
CASENAME	DF_EFFEC	MS_EFFEC	DF_ERROR	MS_ERROR	F	P_LEVEL
1	1,00	301,73	512,00	0,19	1578,65	0,0000
2	1,00	7,37	512,00	0,19	38,58	0,0000
3	1,00	0,17	512,00	0,19	0,89	0,3456
4	1,00	122,17	512,00	0,19	639,18	0,0000
5	1,00	0,45	512,00	0,19	2,38	0,1236
6	1,00	8,68	512,00	0,19	45,42	0,0000
7	1,00	0,13	512,00	0,19	0,68	0,4110
12	1,00	1,03	512,00	0,19	5,41	0,0204
13	1,00	1,08	512,00	0,19	5,65	0,0178
23	1,00	0,82	512,00	0,19	4,26	0,0394
14	1,00	0,10	512,00	0,19	0,51	0,4765
24	1,00	0,01	512,00	0,19	0,07	0,7849
34	1,00	0,59	512,00	0,19	3,08	0,0800
15	1,00	1,23	512,00	0,19	6,41	0,0117
25	1,00	0,52	512,00	0,19	2,73	0,0994
35	1,00	0,05	512,00	0,19	0,26	0,6103
45	1,00	0,00	512,00	0,19	0,00	0,9784
16	1,00	8,80	512,00	0,19	46,03	0,0000
26	1,00	0,67	512,00	0,19	3,49	0,0623
36	1,00	0,04	512,00	0,19	0,21	0,6462
46	1,00	0,13	512,00	0,19	0,69	0,4049
56	1,00	1,65	512,00	0,19	8,63	0,0034
17	1,00	1,85	512,00	0,19	9,67	0,0020
27	1,00	1,87	512,00	0,19	9,78	0,0019
37	1,00	1,31	512,00	0,19	6,86	0,0091
47	1,00	0,27	512,00	0,19	1,42	0,2339
57	1,00	1,65	512,00	0,19	8,61	0,0035
67	1,00	0,45	512,00	0,19	2,35	0,1262
123	1,00	0,43	512,00	0,19	2,24	0,1354
124	1,00	0,95	512,00	0,19	5,00	0,0258
134	1,00	1,50	512,00	0,19	7,85	0,0053
234	1,00	0,90	512,00	0,19	4,69	0,0307
125	1,00	0,02	512,00	0,19	0,11	0,7395
135	1,00	0,01	512,00	0,19	0,05	0,8241
235	1,00	0,91	512,00	0,19	4,74	0,0299
145	1,00	0,27	512,00	0,19	1,42	0,2332
245	1,00	2,76	512,00	0,19	14,46	0,0002
345	1,00	0,47	512,00	0,19	2,44	0,1188
126	1,00	0,00	512,00	0,19	0,01	0,9079
136	1,00	0,03	512,00	0,19	0,16	0,6896
236	1,00	0,10	512,00	0,19	0,53	0,4654

CASENAME	DF_EFFEC	MS_EFFEC	DF_ERROR	MS_ERROR	F	P_LEVEL
146	1,00	0,56	512,00	0,19	2,94	0,0871
246	1,00	1,46	512,00	0,19	7,66	0,0058
346	1,00	0,20	512,00	0,19	1,05	0,3048
156	1,00	0,03	512,00	0,19	0,17	0,6803
256	1,00	0,44	512,00	0,19	2,30	0,1298
356	1,00	0,05	512,00	0,19	0,25	0,6154
456	1,00	0,49	512,00	0,19	2,58	0,1085
127	1,00	0,05	512,00	0,19	0,29	0,5927
137	1,00	0,12	512,00	0,19	0,65	0,4214
237	1,00	0,18	512,00	0,19	0,93	0,3347
147	1,00	1,03	512,00	0,19	5,41	0,0204
247	1,00	0,64	512,00	0,19	3,33	0,0686
347	1,00	1,72	512,00	0,19	9,01	0,0028
157	1,00	0,22	512,00	0,19	1,17	0,2800
257	1,00	0,31	512,00	0,19	1,63	0,2029
357	1,00	0,00	512,00	0,19	0,01	0,9165
457	1,00	0,76	512,00	0,19	3,99	0,0462
167	1,00	0,39	512,00	0,19	2,04	0,1537
267	1,00	0,77	512,00	0,19	4,01	0,0458
367	1,00	0,05	512,00	0,19	0,26	0,6103
467	1,00	0,43	512,00	0,19	2,25	0,1345
567	1,00	0,00	512,00	0,19	0,02	0,8751
1234	1,00	0,05	512,00	0,19	0,26	0,6090
1235	1,00	0,89	512,00	0,19	4,65	0,0314
1245	1,00	0,03	512,00	0,19	0,16	0,6856
1345	1,00	0,44	512,00	0,19	2,31	0,1289
2345	1,00	0,00	512,00	0,19	0,00	0,9568
1236	1,00	0,19	512,00	0,19	1,01	0,3143
1246	1,00	1,08	512,00	0,19	5,66	0,0177
1346	1,00	0,69	512,00	0,19	3,60	0,0584
2346	1,00	2,23	512,00	0,19	11,68	0,0007
1256	1,00	0,23	512,00	0,19	1,22	0,2705
1356	1,00	0,09	512,00	0,19	0,46	0,4957
2356	1,00	0,22	512,00	0,19	1,17	0,2800
1456	1,00	0,46	512,00	0,19	2,43	0,1197
2456	1,00	0,55	512,00	0,19	2,88	0,0901
3456	1,00	0,01	512,00	0,19	0,04	0,8481
1237	1,00	0,57	512,00	0,19	2,97	0,0854
1247	1,00	0,11	512,00	0,19	0,59	0,4415
1347	1,00	0,13	512,00	0,19	0,69	0,4049
2347	1,00	0,00	512,00	0,19	0,00	0,9798
1257	1,00	1,95	512,00	0,19	10,22	0,0015
1357	1,00	0,02	512,00	0,19	0,08	0,7738
2357	1,00	5,81	512,00	0,19	30,42	0,0000

CASENAME	DF_EFFEC	MS_EFFEC	DF_ERROR	MS_ERROR	F	P_LEVEL
1457	1,00	0,03	512,00	0,19	0,16	0,6936
2457	1,00	0,01	512,00	0,19	0,05	0,8241
3457	1,00	0,04	512,00	0,19	0,23	0,6333
1267	1,00	0,27	512,00	0,19	1,39	0,2389
1367	1,00	0,16	512,00	0,19	0,83	0,3635
2367	1,00	4,47	512,00	0,19	23,38	0,0000
1467	1,00	0,70	512,00	0,19	3,69	0,0554
2467	1,00	0,02	512,00	0,19	0,12	0,7272
3467	1,00	0,01	512,00	0,19	0,06	0,8114
1567	1,00	0,19	512,00	0,19	1,00	0,3187
2567	1,00	0,04	512,00	0,19	0,23	0,6294
3567	1,00	0,30	512,00	0,19	1,57	0,2114
4567	1,00	0,45	512,00	0,19	2,37	0,1245
12345	1,00	0,57	512,00	0,19	2,97	0,0854
12346	1,00	0,35	512,00	0,19	1,84	0,1750
12356	1,00	0,15	512,00	0,19	0,77	0,3809
12456	1,00	2,97	512,00	0,19	15,54	0,0001
13456	1,00	0,04	512,00	0,19	0,23	0,6294
23456	1,00	0,54	512,00	0,19	2,83	0,0932
12347	1,00	1,02	512,00	0,19	5,35	0,0211
12357	1,00	0,50	512,00	0,19	2,63	0,1054
12457	1,00	0,16	512,00	0,19	0,82	0,3663
13457	1,00	0,15	512,00	0,19	0,81	0,3692
23457	1,00	1,97	512,00	0,19	10,31	0,0014
12367	1,00	0,15	512,00	0,19	0,79	0,3731
12467	1,00	0,21	512,00	0,19	1,12	0,2914
13467	1,00	0,80	512,00	0,19	4,20	0,0410
23467	1,00	0,26	512,00	0,19	1,37	0,2418
12567	1,00	0,47	512,00	0,19	2,44	0,1188
13567	1,00	1,56	512,00	0,19	8,15	0,0045
23567	1,00	0,31	512,00	0,19	1,61	0,2049
14567	1,00	0,01	512,00	0,19	0,05	0,8311
24567	1,00	0,00	512,00	0,19	0,02	0,8979
34567	1,00	1,18	512,00	0,19	6,19	0,0132
123456	1,00	0,01	512,00	0,19	0,05	0,8241
123457	1,00	0,63	512,00	0,19	3,32	0,0692
123467	1,00	0,10	512,00	0,19	0,51	0,4754
123567	1,00	1,15	512,00	0,19	6,02	0,0145
124567	1,00	2,30	512,00	0,19	12,03	0,0006
134567	1,00	0,06	512,00	0,19	0,30	0,5865
234567	1,00	0,15	512,00	0,19	0,79	0,3760
1234567	1,00	0,65	512,00	0,19	3,42	0,0649

2. Main and interaction effects of the full factorial design

Main effects and interaction effects are calculated as explained in section 4.4. Simulation-based experimental investigation in the doctoral dissertation.

CASENAME	MPDBED	MPDRX	MADCUR
	in %	in %	in days
1:DUE	0,8816	-1,1213	-1,3732
2:CAP	2,5601	1,3803	0,2147
3:LDT	0,6788	0,5005	0,0326
4:SAF	3,5010	-7,7233	0,8738
5:EMERG	0,5842	1,7490	-0,0533
6:CLASS	0,2523	1,1218	0,2329
7:FREQUE	1,5687	-7,9714	0,0284
12	0,0710	0,6850	-0,0804
13	-0,7278	-0,2406	-0,0822
23	0,4853	0,3895	0,0714
14	0,6613	1,6140	-0,0246
24	1,0528	-0,8215	0,0094
34	-0,1018	0,0963	0,0606
15	-0,1319	0,4018	-0,0875
25	-0,7739	-0,7665	-0,0571
35	-0,0870	-0,1708	0,0176
45	-0,1209	-0,6302	-0,0009
16	-0,8978	1,5967	-0,2345
26	-0,6878	0,5987	-0,0646
36	-0,2759	0,1458	-0,0159
46	0,6127	-1,1583	0,0288
56	0,1172	0,8084	0,1016
17	2,2663	-6,2435	0,1075
27	-0,3650	-0,6962	-0,1081
37	-0,5780	-0,9224	-0,0905
47	1,3544	3,3462	0,0412
57	-0,0524	-1,4153	0,1014
67	0,0888	-1,8018	0,0529
123	-0,8177	0,0356	-0,0517
124	-0,1084	-0,8673	0,0772
134	-0,6424	0,5590	-0,0968
234	0,3797	-0,0457	0,0749
125	-0,1430	-0,5470	0,0115
135	-0,2797	-0,2483	0,0077
235	-0,5006	-0,3108	-0,0752
145	-0,1726	-0,0843	-0,0412
245	-0,4881	0,5488	-0,1314
345	-0,1558	0,2441	0,0540
126	0,1292	1,5410	0,0040
136	-0,1903	0,5961	-0,0138

CASENAME	MPDBED	MPDRX	MADCUR
	in %	in %	in days
236	-0,0182	0,4696	0,0253
146	-0,7227	-0,3739	-0,0592
246	-0,6847	0,0510	-0,0957
346	0,1513	-0,0333	0,0355
156	-0,2164	0,2928	0,0143
256	0,2066	-0,1003	0,0524
356	-0,2224	-0,0177	-0,0174
456	0,1352	-0,1705	0,0556
127	0,2621	-0,4019	0,0185
137	-0,1555	-0,2358	0,0278
237	-0,0684	-0,7548	-0,0334
147	0,5938	0,9429	0,0804
247	-0,8092	1,3660	-0,0631
347	-0,3390	0,6055	-0,1038
157	-0,1176	-0,7438	0,0374
257	0,5854	1,1348	0,0441
357	0,1000	0,2938	0,0036
457	1,5122	0,4661	0,0691
167	-0,3631	-1,1928	-0,0494
267	0,1192	-0,7179	-0,0692
367	-0,0800	-0,2127	0,0176
467	0,5687	-0,0337	0,0518
567	-0,2567	-0,0307	0,0054
1234	-0,8651	-0,4537	0,0177
1235	-0,0705	-0,4348	0,0746
1245	-0,2388	0,3675	-0,0140
1345	-0,5604	0,4435	-0,0526
2345	-0,1938	0,1852	0,0019
1236	-0,1569	0,5493	0,0348
1246	-0,3702	-1,1735	0,0822
1346	0,0362	-0,0920	-0,0656
2346	0,4738	-0,1734	0,1181
1256	0,7435	-0,7560	0,0381
1356	-0,4078	-1,3757	0,0236
2356	-0,1802	-0,5000	0,0374
1456	-0,1417	0,1342	-0,0539
2456	0,4898	-0,3340	0,0587
3456	-0,3008	-0,9503	-0,0066
1237	-0,6292	-0,1819	-0,0596
1247	-0,3907	0,2108	0,0266
1347	-0,8165	0,2593	-0,0288
2347	0,0889	0,1409	-0,0009

CASENAME	MPDBED	MPDRX	MADCUR
1257	-0,6768	0,6161	-0,1105
1357	0,1352	-0,1663	-0,0099
2357	0,4091	0,2973	0,1906
1457	0,5493	0,0250	0,0136
2457	-0,1729	-0,7930	0,0077
3457	-0,3674	-0,7843	0,0165
1267	-0,2343	-1,2897	-0,0407
1367	0,1122	-0,8950	-0,0314
2367	0,4208	0,3791	0,1671
1467	-0,4142	1,3423	-0,0664
2467	-0,0352	0,7401	-0,0121
3467	0,2568	-0,2391	0,0083
1567	-0,0013	-0,8179	0,0345
2567	0,2067	0,6651	0,0167
3567	-1,0838	-0,0260	-0,0432
4567	0,2065	0,0227	0,0532
12345	-0,1141	0,4240	0,0596
12346	-0,4630	0,2685	-0,0469
12356	0,0206	-0,9511	0,0303
12456	0,4678	0,0678	0,1362
13456	0,2991	0,3045	0,0167
23456	0,2127	-0,2843	-0,0581
12347	-0,5258	0,7583	-0,0799
12357	-0,3665	0,6490	0,0561
12457	-0,2337	0,2471	-0,0312
13457	0,0014	-0,2795	0,0311
23457	0,3880	-0,4482	0,1110
12367	-0,2082	-0,4481	0,0308
12467	-0,4725	1,2410	-0,0365
13467	0,4014	0,1126	0,0708
23467	-0,0597	-0,5197	0,0405
12567	0,7945	0,1505	0,0540
13567	-0,4514	1,0772	-0,0987
23567	0,2715	-0,3733	0,0439
14567	0,0385	0,1387	0,0074
24567	0,4917	0,5956	0,0044
34567	-0,2944	1,0997	-0,0860
123456	0,3169	-0,4548	0,0077
123457	-0,4044	-0,2578	-0,0629
123467	0,1071	0,1834	-0,0247
123567	-0,2173	0,9805	-0,0848
124567	1,2307	-0,4715	0,1199
134567	-0,2881	-0,1009	-0,0188
234567	0,2045	0,7747	0,0306
1234567	0,4346	0,0845	-0,0639